B 1,304,772

Engin.
TA
406.5
.U57
1946

OP 1681

HANDBOOK OF ORDNANCE RADIOGRAPHY

7 JUNE 1946

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 65 cents

Engineering
Library
TA
406.5
.U57
1946

NAVY DEPARTMENT

BUREAU OF ORDNANCE

WASHINGTON 25, D. C.

7 June 1946

ORDNANCE PAMPHLET 1681

HANDBOOK OF ORDNANCE RADIOGRAPHY

1. Ordnance Pamphlet 1681 is a detailed description of the problems and techniques of ordnance radiography. It contains sufficient theory to explain the functioning of radiographic processes.

2. This handbook has been prepared as a practical daily guide for the use of personnel engaged in the radiographic investigation of ordnance.

G. F. HUSSEY, JR.
Vice Admiral, U. S. Navy
Chief of the Bureau of Ordnance

DEPOSITED BY THE
UNITED STATES OF AMERICA

CONTENTS

		PAGE
1.	Theory of X-Ray Production	1
2.	Interaction of X-Rays and Matter	14
3.	Effects and Uses of X-Radiation	21
4.	X-Ray Film	29
5.	Film Processing	38
6.	Scattering and Filtration	45
7.	Screens	49
8.	Film Defects	53
9.	Radiographic Factors and Techniques	59
10.	Radium	73
11.	Characteristics of the Finished Radiograph	82
12.	Viewing, Stereoscopy, and Reproduction	92
13.	Interpretation of the Radiograph	97
14.	Protection	101
15.	Maintenance and Repair of the Van de Graaff Generator	104
16.	The Operation of the Van de Graaff Generator	139
17.	The Operation of the General Electric OX 400 X-Ray Generator	152
18.	The Operation of the General Elcctric 250 KV Unit	157
19.	The Operation of the Kelley Koett 150 KV Unit	162
20.	The Operation of the General Electric 100 KV Unit	167
21.	The Operation of the 85 KV Waite and Bartlett Medical Unit	170
22.	Special Radiographic Instruments	173
23.	The Geiger Counter X-Ray Spectrometer	182
24.	Supplement	194

DEPOSITED BY THE
UNITED STATES OF AMERICA

Chapter 1

THEORY OF X-RAY PRODUCTION

Structure of the Atom

All the elements are composed of atoms. Chemically they are the smallest structural units, but physically they are assumed to be assemblies of subatomic, electrically charged particles, namely electrons (negatively charged) and nuclei (positively charged). In each atom the positive charge on the central nucleus is equal to the negative charge on the surrounding electrons, but in respect to mass and volume the nucleus and the electrons are unlike by orders of magnitude. The total mass of the electrons of an atom is negligible compared to that of the nucleus, and yet the volume of the nucleus is negligible compared to that of the entire atom.

According to an early model, the atom is mostly empty space, with central nucleus and planetary electrons moving in definite orbits. In the currently accepted model, electrons have only a maximum probability of being intercepted in definite orbits.

If one or more of the electrons is somehow removed from the atom, the atom is said to be ionized and is called a positive ion. Ionization is discussed in detail later. The energy required to ionize an atom depends upon the original state of position and motion of the removed electron or electrons with respect to the attracting nucleus. In the normal atom there are a limited number of these different states of levels of energy each of which can be occupied by electrons of the atom.

The greatest amount of energy (an amount equal to the so-called "binding energy") is required in removing an electron from its K level. The amounts are progressively less for the L, M, N, etc. levels. The levels of lower binding energy are of less interest to the radiographer.

The Nucleus

The structure of the nucleus of the atom, though not as important to the theory of x-ray production as to the understanding of radioactivity, is briefly described, as follows: The nucleus, according to the present model, is an assembly of two kinds of particles of about equal mass. The proton (positively charged) and the neutron (neutral), have the form and consistency of a liquid droplet of inconceivably great density. The nucleus of the atom is usually stable and resistant to extreme physical conditions. However, atoms of the so-called radioactive elements, being unstable, release particles and radiation. These phenomena will be discussed in some detail in Chapter 10.

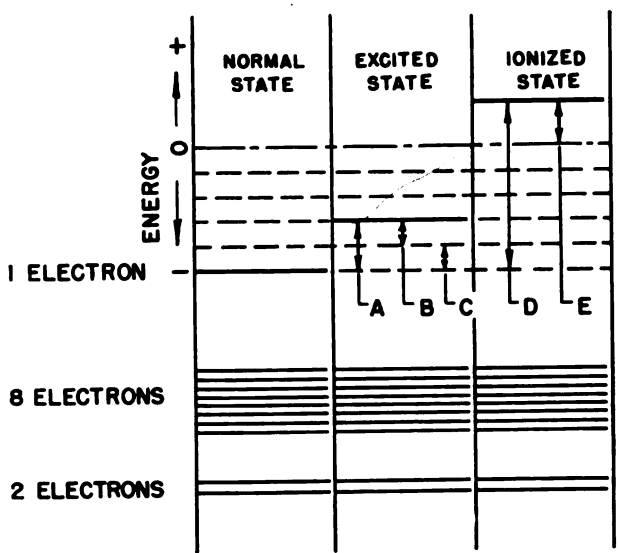


FIGURE 1. Energy level diagram of a sodium atom (atomic number 11). *Left:* Normal state in which eleven electrons occupy the lowest possible levels. *Center:* Excited state in which one electron occupies a level higher than normal. *Right:* Ionized state in which one electron has been displaced beyond the influence of the atom so that the atom is left with a net positive charge. The letters refer to possible electron displacements which result in spectral lines of specific energies

The number of protons in the nucleus or the number of electrons in a neutral atom is called the atomic number of the elements. The average value of the masses of the atoms of any other element (as they occur naturally) relative to the average for oxygen (assumed to be

16) is called the atomic weight of that element. The sum of the number of protons and the number of neutrons assumed to be in combination in the nucleus of an atom is the mass number of that atom. A neutron has very nearly the same mass as a proton, but is electrically neutral.

Perhaps the simplest mechanical analogy of an atom is the Bohr atomic model. An atom of an element, according to this theory, has a central, massive nucleus with a positive charge equal to the atomic number and an equal negative charge consisting of electrons whirling about the nucleus in circular orbits. The number of protons in the nucleus equals the number of electrons in the orbits; the number of neutrons in the nucleus equals the mass number minus the atomic number of the element. The tendency of an electron to fly off from the vicinity of the nucleus is just balanced by the electrical attractive force between the electron and the nucleus. For example, the Bohr model of the lithium atom of mass number 7 and atomic number 3 is shown in Figure 2.

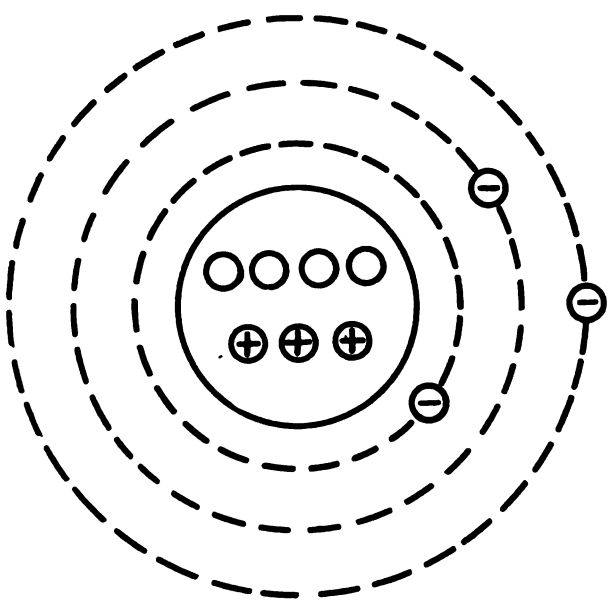


FIGURE 2. Bohr model of lithium atom

This model suggests that the atom is like a miniature solar system. The nucleus is analogous to the sun and the electrons are analogous to the planets, which also rotate about axes similar to the earth's axis. This latter motion is called electron spin. Although this model is satisfactory from a mechanical point of view, it is not completely satisfactory because the theory implies a knowledge of the form of the paths of the electron in the atom, and this has not been revealed by experiments.

Radiation Theories

Radiation is the process of propagating energy by a wave motion through matter or a vacuum. The forms of radiant energy described here apparently travel through evacuated space unchanged, but their travel through matter is marked by transformations of radiant energy into other forms. The various types of radiation include in descending order of wave length, the radiation used in radio broadcasting, heat or infra-red radiation, visible light, ultraviolet radiation, x-rays, gamma rays, and perhaps cosmic rays. It is assumed that these types are basically the same; wave length is their differentiating factor. See Figure 3.

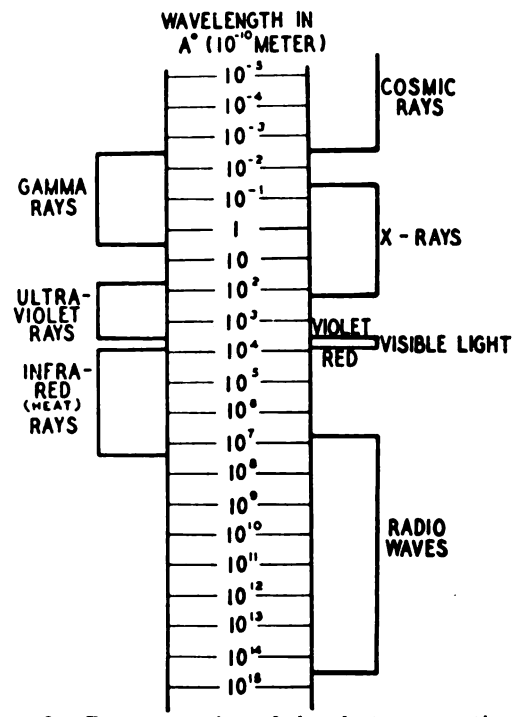


FIGURE 3. Representation of the electromagnetic spectrum in terms of wavelength

Most of these types of radiation have been discovered in the last fifty years. Previously, visible light and heat were the only known radiations, and their similarity was not recognized. The early theories of radiation were based chiefly upon experiments with light.

Some Properties of Radiation to be Explained by Theory

1. Rectilinear Propagation

X-Rays and light travel in a straight line through air or a vacuum.

2. Speed

The speed of light or x-rays in a vacuum is approximately 300,000 kilometers per second, or 186,000 miles per second.

3. Reflection

The reflection of light by a smooth surface such as a mirror is a well-known phenomenon. X-rays behave similarly, though with smaller angles. The angle of incidence is always equal to the angle of reflection, Figure 4.

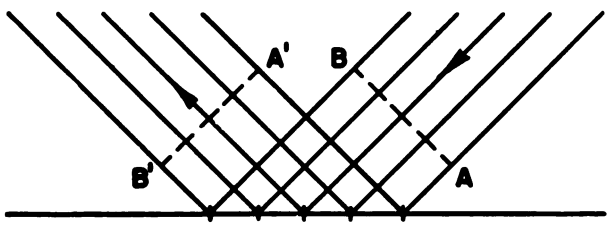


Figure 4. Reflection

4. Refraction

When radiation passes obliquely from one medium to another denser medium, the beam is refracted toward the normal in the denser medium. See Figure 5. A common manifestation of refraction is the apparent bending of a stick partially immersed in water.

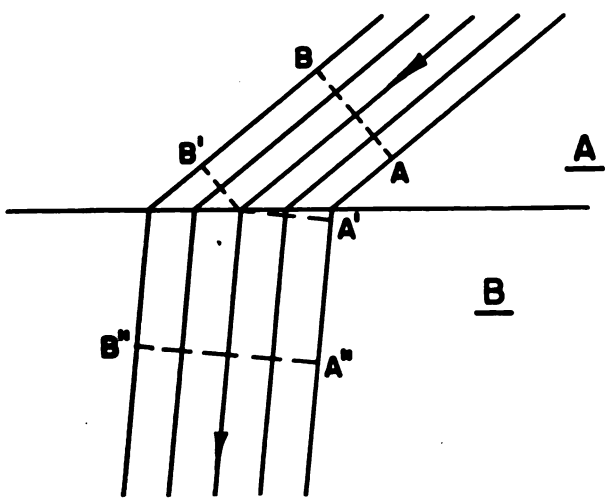


Figure 5. Refraction

5. Diffraction

The phenomenon of the partial or complete interference of light or x-rays can occur during the intersection of the paths of two waves, if the waves have the same source and are out of phase with each other by virtue of an effective difference in the length of their respective paths. See Figure 6.

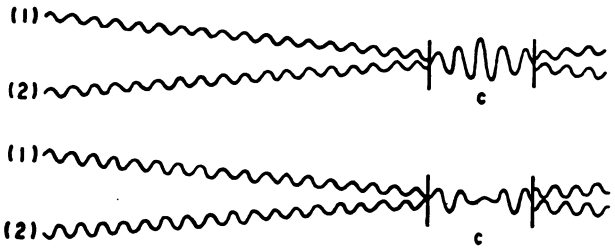


Figure 6. Diagrammatic representation of the reinforcement (*top*) and interference (*bottom*) of two waves 1, 2 intersecting at *C*. In the first case the waves are in phase at *C*; in the second case they are 180° out of phase

6. Polarization

This is a phenomenon by which light or x-rays are polarized after passing through a sheet of minute longitudinal crystals and are blocked or obstructed by a second sheet whose crystals are at 90 degrees to the first, indicating that radiation is a transverse wave and that the vibrations exist in one plane only after traversing the first sheet.

A Transverse Wave

In a transverse wave the particles of the medium move effectively at right angles to the direction of propagation of energy. A familiar example of a wave with a transverse component is a wave on the surface of a pool of water. If a stone is dropped in such a pool, a circular wave spreads out from this point. A cork floating on the water indicates the motion of the particles of the medium. The cork moves not parallel to the original surface of the still water, but bobs up and down. The transverse motion of the cork is vertical while the wave is propagated horizontally. The relations of wave length λ, frequency ν, and velocity c of propagation are expressed by $\lambda = \frac{c}{\nu}$ or wave length $\times$ frequency equals velocity. Under suitable conditions of source and medium, transverse waves may be propagated spherically, etc.

The Electromagnetic Wave Theory

Analyses show that certain motions of electric charges cause the propagation through space of certain interdependent electric and magnetic effects vibrating, in phase, but 90 degrees apart in space, in planes parallel to the direction of propagation. See Figure 7.

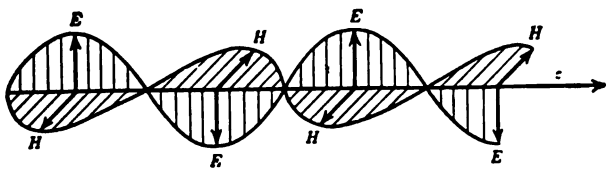


FIGURE 7. Electromagnetic Waves. E=Electric Field; H=Magnetic Field

Energy is propagated by these electromagnetic waves. Perhaps the simplest source of an electromagnetic wave is an electron oscillating in a straight line. The electric and magnetic effects produced at points in the surrounding space by this electron are changing because its position and velocity are changing. The electric and magnetic effects (such as the force on an electric charge) therefore oscillate at the same frequency as the moving electron. Under suitable conditions an electromagnetic wave is initiated in this way.

The energy supplied to maintain the oscillation of the electron is in part propagated out into space. Electrons in the path of the wave are caused to oscillate as the electromagnetic wave passes over them. The frequency of the electromagnetic wave is determined by the frequency of oscillation of the electron which is the source. The velocity, and consequently the wave length, depend upon the medium through which the electromagnetic wave travels. The velocity of any electromagnetic radiation in a vacuum, whatever the frequency, is a constant, about 3×10^8 meters per second.

The Quantum Theory

The German physicist, Planck, developed a hypothesis that was contrary to the electromagnetic wave theory. He assumed that radiant heat was not continuous (i.e., describable by a wave), but was made up of minute "chunks" or quanta of energy radiated in a vacuum with the velocity of light. He assumed that these separate quanta of energy were so small in magnitude (of energy) that the number of them that passed in each second near a point in a radiated space was enormous.

For example, the heat from a 1,000-watt electric heater at a distance of one meter would comprise about 10^{46} quanta per square centimeter per second according to this theory. Planck further assumed that the energy of a quantum of radiant energy could be calculated by multiplying the frequency of the radiation of which it is a part by a universal constant (h), which is called Planck's constant. The frequency that was to be used in this calculation was precisely the frequency that is obtained (under the guidance of the wave theory) by dividing the measured wave length of the radiation into the velocity of light in a vacuum. Thus, the energy (W) of a quantum was assumed to be

$$W = h\nu \text{ joules},$$
$$h = \text{Planck's constant},$$
$$\frac{c}{\lambda} = \nu = \text{frequency}$$
$$\lambda = \text{wave length},$$
$$c = \text{speed}$$

The Dual Nature of Radiation

The quantum theory of radiation has been relatively successful in correlating the experimental data on the interaction of radiation and atoms, such as the photoelectric effect. However, the quantum hypothesis is not as successful as the wave theory in dealing with interference, diffraction, and polarization. Consequently, the wave theory is used to solve problems involving these phenomena. Radiation is assumed to be either a wave or a beam of energy quanta, depending upon which assumption is more convenient for the problem at hand.

Production of X-Rays

Discovery of X-Rays

In December, 1895, Roentgen presented a paper describing his experiments with "a new form of radiation." He detected the presence of this radiation while he was investigating the phenomena that occur in a partially evacuated tube when an electric current flows between electrodes in the tube. Roentgen called the new radiation x-rays, and this name is still

generally used. However, the name Roentgen-rays, suggested as a means of honoring their discoverer, is also used, particularly in relation to the use of the rays in medicine.

Production of X-Rays

Electrons are supplied by a coil of incandescent tungsten wire heated by the passage of an electric current through it. The electrons emitted by the cathode are accelerated in the direction of the anode by the high potential difference applied between the anode (+) and the cathode (—). Thus the velocities and kinetic energies of the electrons increase until they reach the anode where they are suddenly stopped and their kinetic energies transformed into x-rays and heat. The following types of x-rays are produced at any single instant.

1. Minimum Wave Length

When an electron with kinetic energy (Ve) strikes the target of the x-ray tube the energy may be transformed in a variety of ways. The simplest transformation occurs when the electron strikes the nucleus of a target atom. The mass of the nucleus is so great that it is not appreciably disturbed by the impact of the electron. Therefore, the nucleus gains no energy. The electron, however, is stopped by the collision and loses all its kinetic energy.

Since the electron loses its energy and the nucleus gains no energy, the kinetic energy must be transformed into a quantum of radiation. The energy of a quantum of radiation, or photon as it is sometimes called, is hc/λ where h is Planck's constant, c is the velocity of light, and λ is the wave length of the radiation. The energy of the quantum is equal to the kinetic energy of the electron just before it stops so that

$$\frac{hc}{\lambda_{min}} = Ve \text{ joules} \quad \text{or} \quad \lambda_{min} = \frac{hc}{Ve} \text{meters}$$

where λ_{min} = minimum wave length
h = Planck's constant
c = Velocity of light
V = impressed voltage
e = electron charge

Thus the wave length of the radiation produced by the total transformation of the kinetic energy of a moving electron can be calculated if the x-ray tube voltage is known. This equation determines the minimum wave length of x-ray quanta that can be produced. When the values of the constants h, c, and e are substituted, the minimum wave length λ_{min} is

$$\lambda_{min} = \frac{12{,}354}{V} \text{ Å}$$

where Å = Angström unit = 10^{-10} meter and where V is the x-ray tube voltage in volts.

2. Continuous Spectrum

There are very few electrons traversing the space between the cathode and anode that undergo nuclear collisions when they strike the target. Most of the oncoming electrons interact with electrons associated with the target atoms. In this process only a part of the energy of a high-speed electron is required to remove an atomic electron from an atom.

When an impinging electron has lost some of its energy in this way and then is suddenly stopped by an atomic nucleus, the energy that is transformed into an x-ray photon is less than the original kinetic energy, Ve of the electron. The quantum of radiation that is produced in this manner has a wave length greater than λ_{min}. Since the kinetic energy of electrons striking the target may be transformed directly into photons (λ_{min}), or transferred partially to electrons of the target and the remainder subsequently transformed into quanta greater than λ_{min} ($\lambda > \lambda_{min}$), x-rays of many wave lengths are emitted.

X-ray quanta produced by collisions of electrons ejected from target atoms by cathode rays, with atomic nuclei, also contribute to the production of the continuous spectrum. Furthermore, electrons travelling close to nuclei may emit radiation without losing all of their kinetic energies. The spectrum of the x-ray produced in this manner is known as the continuous spectrum. See Figure 9.

3. Characteristic X-Ray Spectral Lines

The x-ray quantum emitted by an atom of an element as the result of the removal of an electron of high binding energy and its subsequent replacement has energy corresponding to a wave length that is characteristic of the element. The x-rays produced in this manner by atoms of the element are called, therefore, char-

acteristic x-rays. The complete spectrum of the x-rays produced in an x-ray tube therefore includes narrow bands of wave lengths for each of which the intensity is greater than for wave lengths adjacent to the band. These bands are produced by characteristic x-rays, and they are made up of characteristic spectral lines.

When an impinging electron having sufficient energy strikes a K electron in a target atom, the K electron acquires kinetic energy from the impinging electron and escapes from the atom. This K level has therefore a vacancy. The atom may return to its normal state by the transition of an electron from some other level to the vacancy in the K level. There are five transitions of this kind and these are shown on the energy level diagram, Figure 8. Each of the five transitions to the K level produces radiation of a particular wave length, and therefore each transition is represented by a single line in the x-ray spectrum. These lines are known as characteristic lines since their wave lengths are determined by the material of the target.

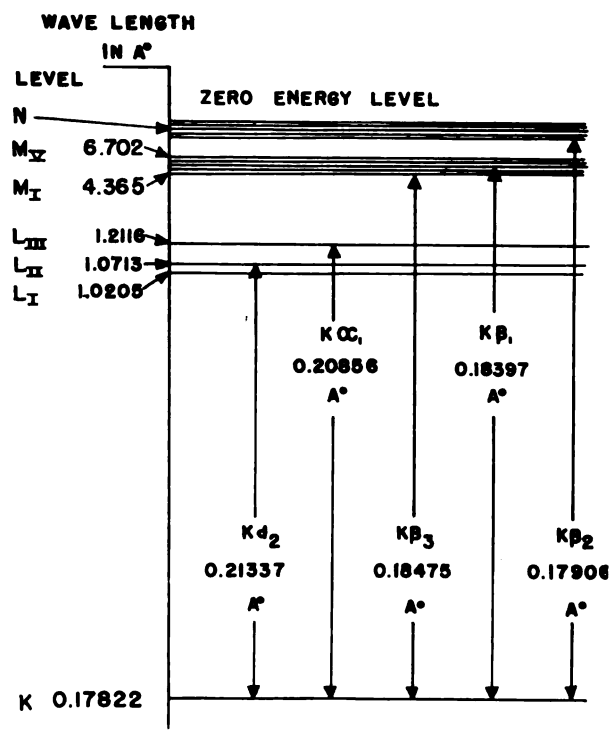


FIGURE 8. Tungsten energy level diagram for the correlation of characteristic spectral lines. Energy levels are designated by wavelengths

The phenomena described above that give rise to the K series also occur when an electron is displaced from any other energy level. Thus there is a series of *characteristic lines* corresponding to each energy level of the target atoms. The series produced by displacement of electrons from the three L levels is sometimes of importance but the M, N, O, etc., series have such long wave lengths and are so easily absorbed by the glass wall of the x-ray tube that they may usually be neglected. The L series is really three separate series arising from the three L energy levels, but since these levels are so close together the resulting characteristic lines are likewise close and the three series are frequently referred to as the L series.

All elements having energy-level distributions similar to that shown for tungsten in Figure 8 have characteristic K and L lines occupying the same relative positions in their spectra. However, the wave length of a particular line has for each element a different wave length. The $K\alpha_1$ line for example, has a wave length for any element that may be calculated approximately from the formula known as Moseley's Law:

$$\lambda K\alpha_1 = \frac{1170}{(A - 1)^2} \text{ Angström Units}$$

where A is the atomic number of the element. In general the wave length of a line having a particular designation such as $K\alpha_1$ decreases as the atomic number increases.

The production of any series of characteristic lines requires an x-ray tube voltage high enough to give the impinging electrons kinetic energy at least equal to the binding energy of the atomic electron that must be displaced in order to produce the series.

4. THE COMPLETE X-RAY SPECTRUM

The production of the continuous x-ray spectrum and the production of the characteristic line spectrum have been described as separate phenomena. In the operation of an x-ray tube both phenomena occur at the same time and the complete x-ray spectrum is of the form but not the quantity shown in Figure 9.

In this complete spectrum the intensity is zero at wave lengths below the minimum wave length λ_{min} which is determined by the x-ray tube voltage. As the wave length increases in the direction indicated by the arrow the in-

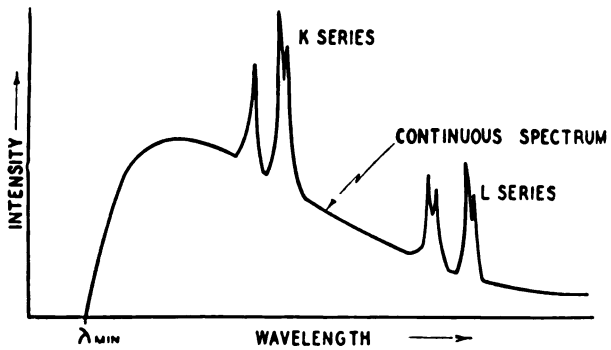


FIGURE 9. General form of the complete x-ray spectrum for an x-ray tube peak voltage considerably higher than that required to produce the K series of the characteristic line spectrum

tensity increases to a maximum and then decreases. The wave length at which the maximum intensity of the continuous spectrum occurs is approximately 1.3 times the minimum wave length.

Beyond the maximum the intensity decreases continuously except at the characteristic wave lengths where it becomes much higher than the intensity of the continuous spectrum adjacent to those wave lengths. The K and L series of characteristic lines are shown on the figure. If the measured x-ray beam has not passed through an absorbing substance such as glass, the M series may be found to the right of the L series.

Heat and the Efficiency of X-Ray Production

When a cathode ray electron strikes the target of an x-ray tube it most likely will lose its energy by processes which may be described as collisions with the electrons in the atoms of the target. Practically all of this lost energy ultimately appears in the heating of the target. These multiple collisions displace electrons from levels of high binding energy to lower levels and may eject low energy electrons. In returning to their original orbits or energy levels smaller quanta of energy are omitted than are required to produce x-rays. These lower energy or longer wave length photons are emitted as heat.

The heat loss is large as may be seen from the following formula for efficiency in percent of x-ray production:

$$E = 1.1 \times 10^{-7}\ ZV$$

where E = efficiency in percent
Z = atomic number of target
V = tube potential

For a tungsten target at 100 KV the efficiency of x-ray production is 0.8 percent. For a tungsten target of 400 KV the efficiency is 3.26 percent.

From the formula it is evident that the higher the atomic number of the target and the higher the impressed voltage, the higher is the efficiency of x-ray production.

Formulae

1. Energy of a quantum of radiation or a photon is equal to kinetic energy of electron.

$$Ve \text{ joules} = \text{energy of photon} = \frac{hc}{\lambda}$$

h = Planck's constant = 6.55×10^{-34} erg. sec.
λ = x-ray wave length in Angström units

2. Therefore the minimum wave length possible is

$$\lambda_{min} = \frac{12354}{V} \text{ Angström}$$

Angström unit = 10^{-8} cm.

3. In the continuous spectrum the peak of the curve, or point of highest x-ray intensity, is

λ of greatest intensity = $1.3 \times \lambda_{min}$
effective voltage = $.7 \times$ peak voltage
(Kramer's Law)

Theory of Low-Voltage Production of X-Rays

X-rays are produced when electrons, traveling at high speed, collide with matter in any form. In the usual form of x-ray tube, an incandescent filament supplies the electrons. This filament is the cathode, or negative electrode, of the tube. A high voltage applied to the tube drives the electrons to the anode, or target, thereby generating the x-rays. The design and spacing of the electrodes, and the degree of vacuum, are such that no electrical discharge between cathode and anode is possible until the filament of the cathode is heated.

Figure 10 is a schematic diagram of the essential parts of an x-ray tube. The filament

is heated by a current of several amperes from a low voltage source, generally a small transformer. The focusing cup serves to concentrate the stream of electrons on a small area of the target, called the focal spot. This stream of electrons constitutes the tube current, and is measured in milliamperes.

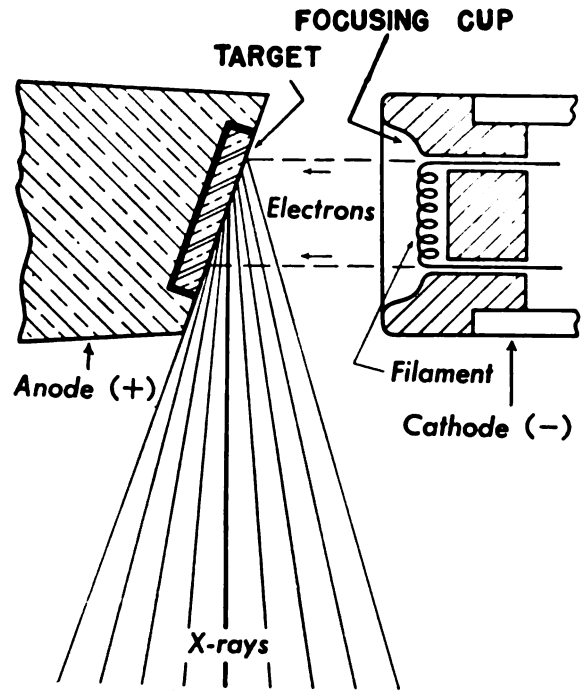


FIGURE 10. Diagram of x-ray tube

The higher the temperature of the filament, the greater is its emission of electrons, and the larger the resulting tube current. The tube current is controlled, therefore, by some device which regulates the heating current supplied to the filament, and this is accomplished usually by a choke coil or variable resistor in the primary circuit of the filament transformer. Other conditions remaining the same, the x-ray output is proportional to the tube current.

Most of the energy applied to the tube for the production of x-rays is transformed into heat at the focal spot. This high concentration of heat in a small area imposes a severe burden on the materials and design of the anode. The efficiency of the target material in the production of x-rays is proportional to its atomic number. The high atomic number of tungsten, in combination with its high melting point, makes it a suitable material for the target of an x-ray tube.

Circulation of water or oil in the interior of the anode is an effective method of carrying away the heat. In the absence of provision for liquid cooling, the use of copper for the main body of the anode provides high heat conductivity, while radiating fins on the end of the anode outside the tube transfer the heat to the surrounding oil or air.

The focal spot should be as small as conditions permit, in order to secure the sharpest possible definition in the radiographic image. The smaller the focal spot, the less energy it will withstand without damage. Manufacturers of x-ray tubes furnish data in the form of charts indicating the kilovoltages and milliamperages that may be safely applied at various exposure times, and the life of any tube will be prolonged considerably if it is always operated within the rated capacity.

A focal spot of small effective size, though the actual focal area on the anode face may be fairly large, is provided by the principle of the line focus, illustrated in Figue 11.

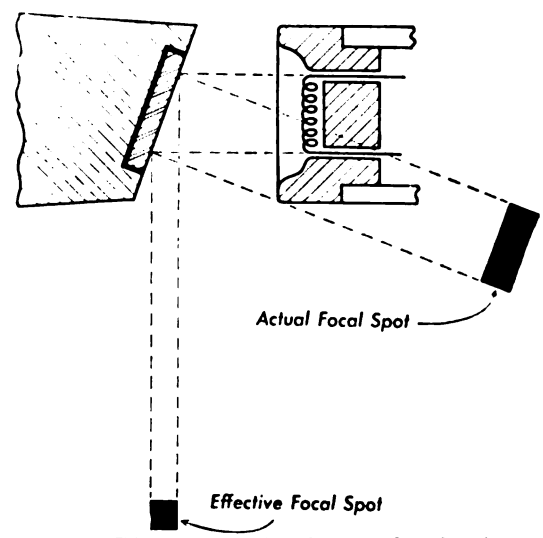


FIGURE 11. Diagram of line-focus tube showing relation between actual focal spot (area of bombardment) and effective focal spot, as projected from a 20° anode

By making the angle between anode face and central ray small, usually 20 degrees, the effective area of the spot is only a fraction of its actual area. With the focal area in the form of a long rectangle, as shown, the projected area, in the direction of the central ray, is square.

As will be seen later, different voltages are applied to the x-ray tube to meet the demands of various classes of radiographic work. The higher the voltage, the greater the speed of the electrons striking the focal spot. The result is a decrease in wave length of the x-rays emitted and an increase in their intensity, and in their penetrating power. The x-rays produced, for example, at 200 kilovolts contain all of the wave lengths that would be produced at 100 kilovolts, and with greater intensity. In addition, the 200-kilovolt x-rays include some shorter wave lengths which did not exist in the 100-kilovolt spectrum at all. The higher voltage x-rays are used for the penetration of thicker and heavier materials.

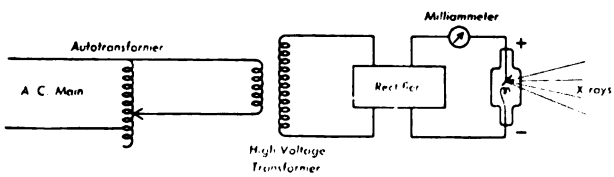


FIGURE 12. Principal electrical features of an x-ray machine

Figure 12 is a schematic diagram of x-ray generating apparatus. The connection of an autotransformer to the alternating current main makes possible the adjustment of voltage applied to the high-voltage x-ray transformer to suit the work at hand. This high-voltage transformer usually raises the applied voltage by a factor of 1,000 or more.

The relation between current and voltage in the transformer is that $E_1 I_1 = E_2 I_2$, where $E_1 I_1$ and $E_2 I_2$ are the products of voltage and current in the primary and secondary windings of the transformer, respectively. For example, if E_1 is 200 volts and I_1 is 5 amperes, 200 volts $\times$ 5 amperes = 200,000 volts $\times$ 0.005 ampere.

Another way of expressing the output in this case is to say that the secondary side of the transformer is delivering 5 milliamperes at 200 kilovolts. The product gives 1000 watts, which is the power input of the transformer. This equation assumes, of course, that the transformer is 100% efficient. Actually, it is not possible to obtain as much power on the secondary high voltage side of the transformer as is applied to the primary low voltage side.

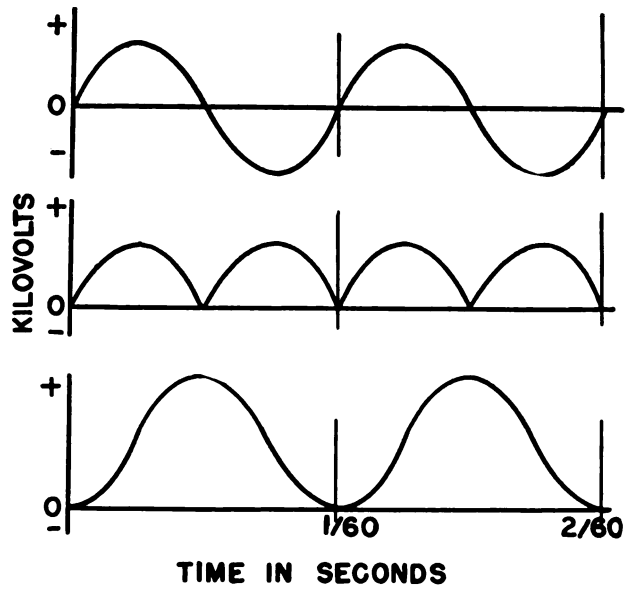
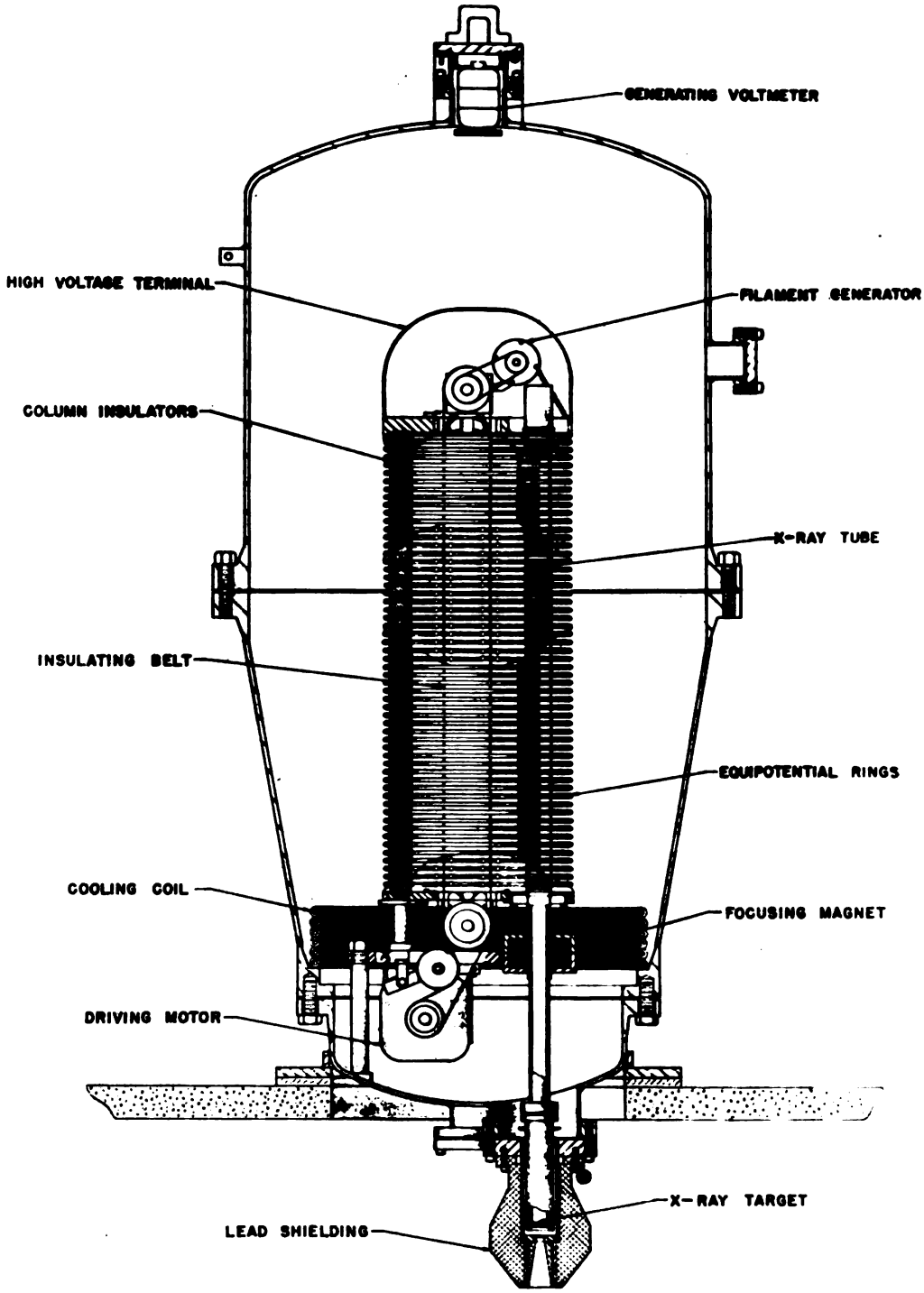


FIGURE 13. Types of x-ray machine voltage wave forms

The type of voltage wave form supplied by the high-voltage transformer is shown in Figure 13A and consists of alternating pulses, first in one direction and then in the other. Generally speaking, this is not suitable for direct application to the x-ray tube. The high voltage is therefore supplied to a unit called a rectifier which converts the pulses into the unidirectional form illustrated in Figure 13B. Another type of rectifier may convert the wave form to that of Figue 13C, but the general idea is the same in both cases, i.e., unidirectional voltage is supplied to the x-ray tube.

Recent developments of industrial x-ray tubes have made possible the direct application of the high voltage wave form of Figure 13A to the x-ray tube, which acts as its own rectifier. The milliammeter indicates the current flowing through the x-ray tube. No attempt is made here to discuss the various forms of electrical generating equipment. The essential fact is that high voltage is required at the terminals of the x-ray tube.

In developing suitable exposure technique, it is important to know the voltage applied to the x-ray tube. It is common practice for manufacturers of x-ray equipment to calibrate their machines at the factory so that the operator may know the voltage across the x-ray tube from the reading of the voltmeter connected to



HIGH VOLTAGE X-RAY GENERATOR

FIGURE 14. Electrostatic high-voltage x-ray generator

the primary of the high-voltage transformer. Furthermore, in modern x-ray generators, the tube is entirely enclosed within a shock-proof container, so that the tube terminals are not accessible for calibration purposes.

Theory of High Voltage Generators

Van de Graaff: The operation of the electrostatic generator, Figure 14, depends upon the fact that when there is an unequal distribution of electric charges between conductors there will be a difference of potential between them. The size of this difference depends upon the efficiency of the insulation between the conductors. In this generator the insulation is dry air at high pressure (200 lbs. per sq. in.). An endless belt made of insulating material runs between a pulley inside the high voltage terminal and a pulley at the ground potential at the base of the machine.

Opposite the lower pulley is a row of sharp needle points which are maintained at a negative potential, usually by a transformer-rectifier. If this potential is high enough, the electric field at the points becomes high enough to ionize the air in the space between them and the pulley.

Under these conditions, the negative charges in the ionized air tend to move away from the negative points and towards the pulley. On their way, however, they are intercepted by the moving belt, and since it is an insulator, they remain on its surface and are carried by it to the insulated terminal. After the part of the belt carrying this charge has entered the terminal, but before it has gone over the upper pulley, it passes by another row of points connected to the terminal.

Since there is an electric field at the surface of the belt due to the charges on it, and this field is concentrated on the points when the belt passes them, the air in this region is also ionized and charge passes between the belt and this set of points. In this case the negative charge passes from the negatively charged belt to the points. This charge rapidly accumulates on the terminal, and, since the process is continuous, the terminal becomes more and more negative with respect to its surroundings.

The potential of the terminal thus increases until a voltage is reached where either the insulation of the air surrounding it is broken down or where the rate at which the charge leaks away over the insulating supports equals the rate at which the charge is brought up by the moving belt. The rate at which the charge leaks away depends, of course, on the potential of the terminal.

The generator is housed in a steel pressure vessel, the wall of which forms the outer grounded surface. The terminal is supported and insulated by a stack of column insulators which also support a series of metal equipotential rings. The rings divide the column into 57 separate electrical regions, in each of which the electric field is approximately uniform.

The lower pulley is driven by an electric motor of sufficient power to move the belt against the electric forces on it and to overcome the frictional losses which develop when the belt moves at high speed in the high pressure air. The voltage generated is insulated by the solid insulators in the column and by the air in the tank which is at a pressure of 200 pounds per square inch. The x-ray tube is inserted in the column with the filament end connected to the negative terminal, and the target end at ground potential. The target itself is insulated so that the current to ground can be measured. Power is supplied to heat the filament by a small auxiliary permanent magnet generator located in the terminal and driven by the rotating upper pulley.

Resonance Type Generator

The resonance type generator, as built by the General Electric Company, embodies a resonant transformer system tuned to a frequency of 180 cycles obtained from a motor generator set. The transformer does not have a core through the coils, and the space usually occupied by the core is occupied by the x-ray tube. The only transformer iron used in the transformer is placed outside the coils and just inside the wall of the cylindrical steel tank. Because of the absence of iron in the transformer and also because a gas is used for insulation instead of the usual transformer oil, the construction is exceptionally light in weight in comparison with its capacity. One hundred

pounds of "freon" gas (CH_2F_2) perform an insulating function which would require 6 tons of oil, if oil were used instead. The transformer is housed within a cylindrical steel tank approximately 4 feet in diameter and 7 feet in length with the extension chamber of the x-ray tube projecting from the bottom.

The output of the D.C. generator in the motor generator set, through a motor driven rheostat, supplies the field current to the alternator whose output is then supplied to a high voltage transformer.

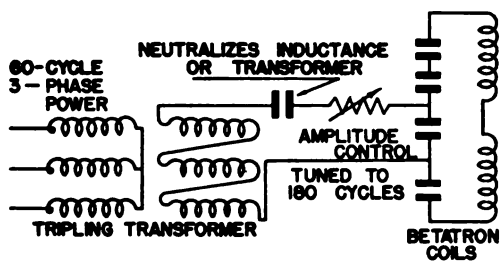
The x-ray tube is a multisection tube and operates with the anode at ground potential. The tube is located at the center of the tubehead, inside the secondary coils of the high-voltage transformer, and the anode end projects through the bottom of the tubehead.

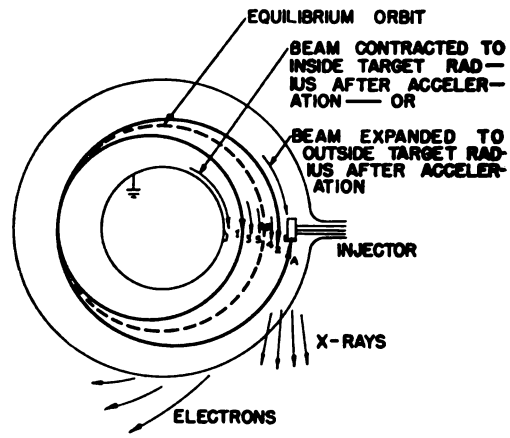
The 20 M.E.V. Betatron

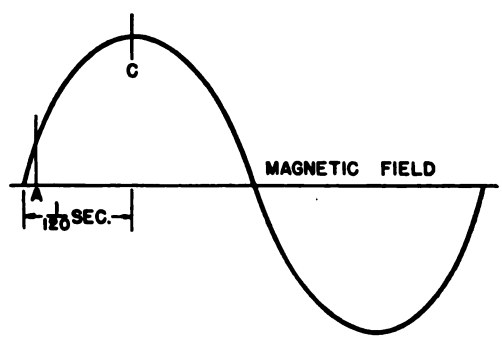
It is an experimental fact that the force on an electron moving in a uniform magnetic field, always acts along a line perpendicular to both the direction of motion of the electron and the direction of the magnetic field. If an electron enters the space between two parallel plane magnetic poles, moving parallel to the pole faces at constant speed, it travels subsequently in a circle parallel to the pole faces.

The betatron is a machine which accelerates electrons by magnetic induction to very high energies and causes them to impinge on a small platinum target. The x-rays which are produced emerge from the tube in a narrow cone.

The 20 M.E.V. Betatron has an alterating current magnet (weighing 3.5 tons) made of laminated iron and has 19-inch diameter circu-







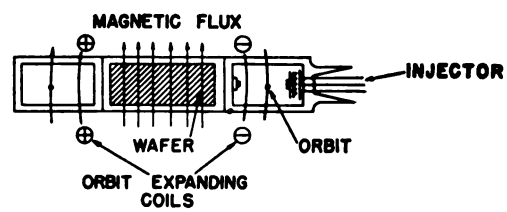


FIGURE 15. Electrons are injected at time *A* in the magnetic cycle and directed at time *C* against either an inside target (if wafer saturates) or an outside target (by use of expander coils and non-saturating wafer)

lar pole pieces. By the use of a frequency tripling transformer or a motor generator set, the input three phase power is transformed to single phase 180-cycle power which is fed to a resonant circuit which is made up of the magnet coils and a 180 kva capacitor bank. The whole unit consumes about 25 kw. A simplified wiring diagram is shown in Figure 15.

A toroidal or doughnut-shaped vacuum tube is placed in the field. Electrons are injected tangentially from a gun, called the injector, within the tube shortly after the alternating magnetic field has passed through zero. As the field increases, the electrons are accelerated around the tube, gaining about 65 electron-volts energy on each revolution. The field is so shaped as to bring the electrons quickly to a nearly circular path called the equilibrium orbit.

The relation of the magnetic field and vacuum tube and the electronic motions are shown schematically in Figure 15.

As the electrons attain an energy of 20 M.E.V. the field conditions which hold the electrons in the equilibrium orbit are upset and the electrons are brought to the target. Two methods of accomplishing this are used. In one the amount of iron in the "wafer" between the poles is adjusted so that it saturates magnetically as the field approaches its maximum value, and the electrons spiral in to an inside target. In the other a condenser is discharged in such a direction through one-turn coils attached to each pole face that the electrons spiral out to strike a target attached to the injector. The x-ray output is 25 to 90 roentgens per minute.

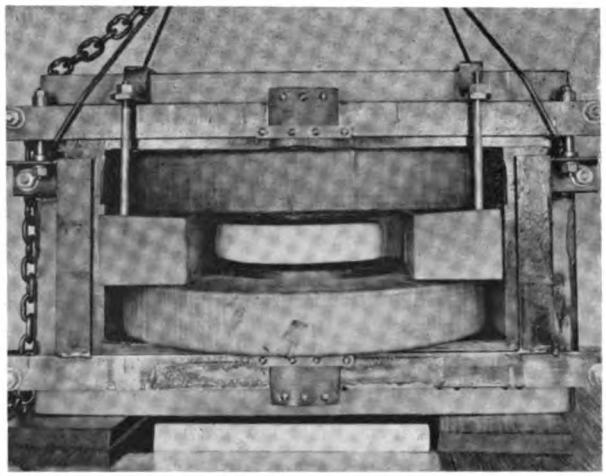


FIGURE 16. A 4.5 M.E.V. Betatron

A 4.5 M.E.V. Betatron has also been built and is shown in the accompanying photograph, Figure 16. The toroidal vacuum tube, or "doughnut," is constructed of porcelain and is sealed off.

699810—46—2

Chapter 2

INTERACTION OF X-RAYS AND MATTER

The preceding chapter is a discussion of the production of x-rays at the target of an x-ray tube. The x-rays are radiated into the space surrounding the target. Next it is important to discuss what happens when x-rays strike matter.

In Figure 17 the arrow marked "incident beam" represents a narrow beam of monochromatic x-rays directed at a block of some substance. The effects of the beam's striking the block are described below.

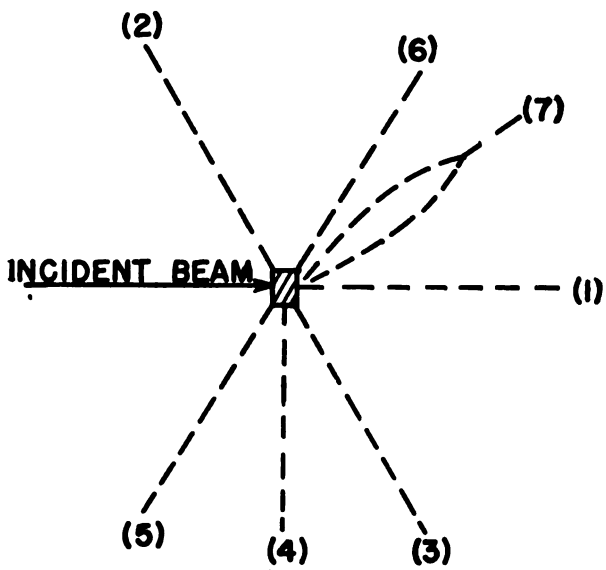


FIGURE 17. Diagrammatic representation of the interaction of x-rays and matter. The radiation and the electrons emitted by an irradiated body are:

1. Attenuated primary x-rays
2. Characteristic x-rays
3. Photoelectrons
4. Unmodified scattered x-rays
5. Modified scattering
6. Recoil electrons
7. Pair production

When x-rays strike matter the following effects may be noted:

1. The incident primary beam continues in a straight line through the block with decreased intensity.

2. X-rays having characteristic wave lengths of the substance are emitted in all directions.

3. Electrons whose ejection from atoms give rise to characteristic x-rays are emitted in all directions. As the wave length of the primary beam is decreased, spatial distribution is predominantly in the forward direction (in the direction of the primary x-ray beam). They are known as *"photoelectrons."*

4. Radiation of the same wave length as the primary beam is emitted in all directions. This process is known as unmodified scattering.

5. Radiation having wave lengths longer than that of the primary beam is scattered in all directions. The wave length of the scattered radiation increases with the angle between the scattered ray and the incident ray. This process is "Compton scattering."

6. Electrons are emitted with varying velocities but always with a component in the forward direction. The greater the forward component, the greater the velocity. These electrons are known as "Compton" or "recoil electrons." They have a lower average velocity than photoelectrons.

7. At high voltages (1.5 M.E.V. and up), positron-electron pairs are created by the transformation of the x-ray quanta in the vicinity of heavy nuclei (positron-positively charged particle having the same mass as an electron). This transformation of radiant energy into mass occurs only when short wave length radiation falls upon heavy elements. The positron combines with the same or another electron to form another x-ray photon.

Total Absorption in Matter

It is evident that the process of diminution of energy of x-rays and of gamma rays as they traverse matter is complex and depends on many transformations of the original energy. It does not lend itself easily to analysis by calculation, unless certain limiting assumptions are made, to simplify these conditions. The

amount of radiation absorbed in a medium depends on (1) wave length of radiation and (2) the kind and number of atoms contained in the absorber. For homogeneous radiation, that is, radiation of one wave length, and for a homogeneous absorber, such as a sheet of pure copper, the fundamental law of absorption is an exponential law, given by the formula:

$I = I_o e^{-\mu d}$ d = thickness in cm.

where I_o is the intensity of the roentgen beam falling on an absorber of the thickness d, and I the intensity of the beam after it emerges from the absorber; μ is the linear absorption coefficient and e is the base of the natural system of logarithms (2.718). For ordinary logarithms to the base of 10, the formula solved for the coefficient of absorption, μ, reads:

$$\mu = \frac{\log I_o - \log I}{0.4343 \times d}$$

This absorption coefficient is the same for various thicknesses of absorbing materials as long as homogeneous radiation is used. Unfortunately, radiation beams used in radiology are heterogeneous. It is also possible, of course, to measure the radiation intensity falling on and emerging from an absorber for a heterogeneous beam and to calculate a "coefficient of absorption," μ. The value thus obtained, however, will be an average coefficient of absorption, dependent on all the factors enumerated, that is, photoelectric absorption, Compton absorption, and so forth, for various wave lengths. Its value will change with increased thickness of the absorber, because of the change in quality of heterogeneous radiation with depth of penetration. For homogeneous radiation, an absorption curve, that is, a representation of the decrease of radiation intensity with increasing absorber thickness, is a straight line on semi-logarithmic graph paper; but the graph for heterogeneous radiation is a curve which approaches a straight line only if the radiation has gone through sufficient absorbing material to "harden" it considerably, thus making it approach homogeneity. Such absorption curves will be demonstrated for measurement of radiation qualities. Another interesting relationship between absorption curves and methods of measuring radiation quality is obtained in an absorbing layer which absorbs just one-half of the impinging radiation. In that case,

$\frac{I}{I_o} = \frac{1}{2}$, the formula resolves itself into

$$\mu = \frac{\log 100 - \log 50}{0.4343 \times d} = \frac{2.0 - 1.6990}{.4343 \times d}$$

$\mu \times d = 0.0695$

$d = HVL = \frac{.695}{\mu}$ HVL = half value layer, thickness in cm.

This value HVL, that is, the absorbing layer of a material which reduces the intensity of a radiation beam to one-half its original value, is called half-value layer.

Mass Absorption Coefficient

The linear absorption coefficient μ for any substance depends upon the state—solid, liquid, or gaseous, of the substance. For example, the intensity of an x-ray beam is not decreased as much by traversing 1 centimeter of steam as it is by passing through 1 centimeter of water. However, the linear absorption coefficient μ divided by the density of the substance ρ (rho) is the same regardless of the physical or chemical state of the substance. Therefore, μ/ρ (mu over rho) specifies the x-ray absorption of the substance in any state for a given x-ray wave length. This ratio μ/ρ is known as the mass absorption coefficient, and it is the fraction of the intensity lost per unit mass thickness.

The formula becomes:

$I = I_o e^{-\mu/\rho \cdot \rho d}$

ρ is density in grams/centimeter^3

d is thickness in centimeters

μ/ρ is mass absorption coefficient in cm^2/ gm

Problem

What percentage of gamma radiation will penetrate 3 inches of lead?

$I = I_o e^{-\mu/\rho \cdot \rho d}$

From table mass absorption coefficient of Pb μ/ρ is .0425

$\frac{I}{I_o} = e^{-\mu/\rho \cdot \rho d}$

$\frac{I}{I_o} = e^{-(.0425 \times 11 \times 3 \times 2.54)}$

d = 3 inches

1 in. = 2.54 cm.

density of Pb = 11.0

$= e^{-(.4675 \times 7.62)}$

$= e^{-(3.58)}$ (values for e^{-x} found in table)

$= .027876$

$\frac{100\ I}{I_o} = 2.8\%$, or 2.8% of the original gamma radiation traverses 3 inches of lead.

The mass absorption coefficient for kilovoltages from 20 KV to 2 M.E.V. is given in table for various absorbers.

Components of Total Absorption

The interaction of x-rays with matter is mainly an interaction with electrons and nuclei. Three essentially different types of phenomena have been distinguished: the photoelectric effect, the Compton effect or scattering by free electrons, and the creation of positron-electron pairs. The relative importance of these three processes depends upon the energy of the x-ray quantum and the atomic number of the absorbing element.

As shown above, the intensity of a monochromatic beam passing through matter decreases exponentially:

$$I = I_o e^{-\mu d}$$

where the absorption coefficient represents the average number of absorption and scattering process which a single quantum undergoes per cm. path. μ is composed additively of three parts referring to the three processes:

$$\mu = \mu \text{ phot} + \mu \text{ Compt} + \mu \text{ pair}$$

Photoelectric Absorption, Characteristic X-Rays and Critical Absorption Wave Length

Photoelectric absorption produces characteristic x-rays and photoelectrons in the same manner that they are produced in the x-ray tube except that the source of energy for ionizing each atom is a photon instead of a high speed electron. The photon strikes the electron of the atom and ejects it as a photoelectron. All the energy of the incident photon is transformed into energy for releasing the electron from the atom and in giving it kinetic energy. When the unoccupied energy level is subsequently filled by an electron from another energy level, a photon having one of the characteristic wave lengths is emitted. In this manner the characteristic spectra of the element are produced. Thus the same characteristic K-, L-, M-, N-series of lines are produced by high-speed electrons or photons of corresponding energies. See Figure 18.

The wave lengths of the primary beam at which the characteristic series start are known as the critical absorption wave lengths.

Since a photon is electrically neutral, it may travel through the molecules of air for a considerable distance before it actually collides with a gaseous atom. The electron, however, in contrast to the photon, has a definite negative electrical charge. Hence it has many more chances than the photon to collide with other particles, when traveling through the electrical fields of atoms. The result is that the photo-electron produces along its path a series of ions, whose number depends on its original energy. Even in air, most photoelectrons are stopped completely within a few centimeters, but along this path, not straight but zigzag, several thousand ion pairs may be formed.

The photoelectric effect plays in general an important part in the absorption of x-rays and x-ray matter. For heavy elements and soft radiation almost all the absorption is due to this effect. It gives an appreciable absorption even if the primary energy is very much greater than the ionization energy of the atom.

Photoelectric effect increases with mass and decreases with increased voltage:

Pb	.5 M.E.V.	— 50%;
Pb	1.0 M.E.V.	— 30%;
Fe	1.0 M.E.V.	— 1%.

It is thus apparent that the photoelectric effect must not be neglected when longer wave length radiation than that due to 1 M.E.V. is considered. Since an x-ray tube produces a continuous spectrum of x-rays and that spectrum has a maximum at an energy lower than the short wave length limit, the protoelectric effect enters to a certain extent for all the tube voltages used in radiography now.

No simple formula can be given for μ photoelectric as a function of atomic number Z over the whole wave length range; however, the mass photoelectric absorption coefficient be-

tween any two absorption wave lengths can be written:

$$\mu \text{ photo} = \frac{C}{A} Z^4 X^3$$

in which

A is atomic number
Z is atomic weight
X is wave length
C is constant between two

critical absorption wave lengths, but changes value at each critical absorption wave length (see Figure 18). In general this equation shows that the photoelectric absorption is large for heavy elements and long wave lengths and small for light elements and short wave lengths.

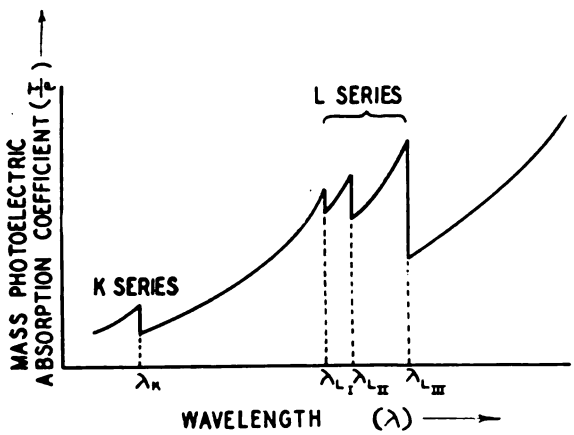


FIGURE 18. General form of relation between the mass photoelectric absorption coefficient τ/ρ and the wave length λ

X-Ray Scattering

X-ray scattering consists of two types: unmodified and Compton scattering.

Unmodified

The first type is unmodified scattering, resulting in the emission in all directions of secondary radiation of the same wave lengths as the primary beam. Unmodified scattering occurs when photons of the primary beam interact with atomic nuclei or bound electrons. Bound electrons are those requiring more energy for their ejection than the oncoming photons possess. In this process of collision with a bound electron or nucleus a photon does not lose energy but bounces off with the same energy and wave length it had before collision. Only the direction of the photon is changed. Unmodified scattering is very appreciable for long wave length x-rays, in heavy elements. For light elements and short wave lengths it is negligible.

Compton Scattering and Compton Absorption

With increasing potential at the x-ray tube, which imparts increased energy to the photons, production of photoelectrons decreases rapidly, and another type of encounter between photon and atom appears.

In this type of collision, the photon also strikes an electron traveling in one of the orbits around the nucleus. In this case, however, it gives up only a part of its energy to the electron, and is itself deviated from its path in the process (Figure 19C, D).

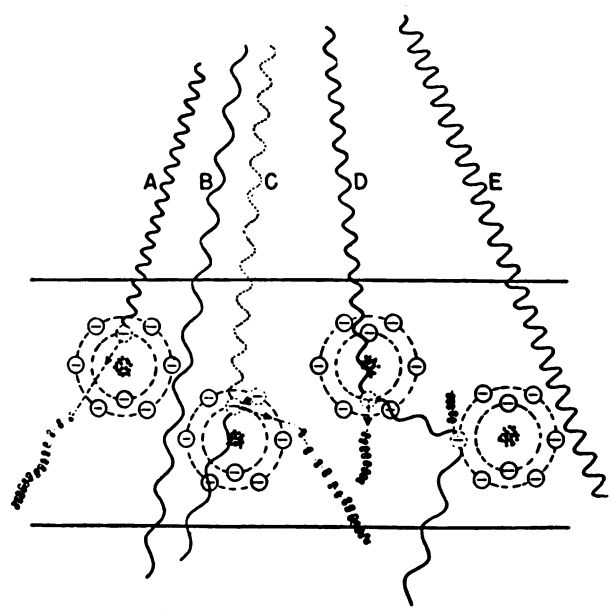


FIGURE 19. *A*. Photoelectric absorption and photoelectron emission. *B and E*. Diminished primary beam. *C*. Compton scatter and Compton recoil electron. *D*. Same as *C* plus a second similar collision

The energy of the photon is transferred into three forms: (1) the potential energy of the ionized atom (obtained from the photon in ejecting the electron), small in comparison to the total energy of the electron, (2) the kinetic energy of the recoil electron, and (3) the energy of the scattered photon which has less energy and therefore a longer wave length than the incident photon. The scattered photon proceeds at an angle Θ (theta) with the direction of the incident photon. The photon may be scattered

in any direction but the recoil electron always has a forward component of velocity.

This type of encounter is called a Compton collision and the removed electron is called a Compton electron. As would be expected, the scattered photon may have secondary or even tertiary Compton collisions and eject more and more Compton or recoil electrons until its energy finally is spent. All these electrons form series of ions along their paths.

Compton scattering makes by far the largest contribution to the total absorption coefficient in the energy range from 0.5 M.E.V. to 2.0 M.E.V. The difference in wave length between the primary photon and the scattered photon can be calculated immediately from the equation expressing the conservation of energy and momentum. This relation between the wave length (λ) of the primary quantum and the angle between the velocities of the two quanta is the well known Compton formula:

$$\lambda_1 - \lambda_2 = \Delta\lambda$$

$$\Delta\lambda = \frac{h}{mc}(I - \cos\Theta)\,\text{Å}$$

$$\frac{h}{mc} = .024$$

where h represents Planck's constant, m represents the electronic mass, and c represents the velocity of light. This relation states that the increase in wave length for the radiation scattered through a given angle is independent of the wave length of the primary quantum. The effect is particularly important in the case of high frequency radiation, since the radiation of however small an initial wave length, can acquire in a single scattering process, a wave length of the order of magnitude of

$$\frac{h}{mc} = .024 = .51 \text{ M.E.V.}$$

Owing to the assumption that all electrons scatter as free electrons, the total Compton cross section U Compt is given by:

$$U \text{ Compt} = NZ\sigma e$$

where σe = scattering coefficient for single electron, NZ is the number of electrons per cm^3, Z representing atomic number and N the number of atoms per cm^3. For a comparison with theory it is better to make use only of those measurements for which photoelectric absorption and pair production are small compared with the absorption due to scattering.

As a function of atomic number Z, the total absorption coefficient can be expressed most simply in the region where the Compton scattering gives the only contribution. μ in this region is proportional to the total number of electrons NZ per cm^3. Since Z is roughly proportional to the atomic weight, μ is to the same extent proportional to the density ρ. Thus the total intensity absorbed is proportional to the mass per cm^2 through which the x-ray has passed. It is then possible to define for this region a mass absorption coefficient $\mu \frac{(\text{cm}^2)}{\text{gm}}$ which is roughly constant for all elements at a given energy.

Pair Production

Photons of extremely high energies (produced at more than a million volts) may undergo transformations of their whole energy into a positron and an electron; this can occur only very close to the nucleus of an atom. Both of these particles travel with high velocities, again forming ions in their paths. However, the positron may reunite with an electron, to form another photon of high energy. This is a possibility only when high energy photons and absorbers of high atomic number are used.

As the self-energy of an electron is mc^2, a minimum energy of 2mc^2 (1.02 M.E.V.) must be supplied by the x-ray photon. Because of this minimum energy requirement pair production does not occur for photon energies less than 2mc^2, and it becomes an important absorption process only at somewhat higher energies. This function increases rapidly with higher energies. At 2 M.E.V. absorption due to pair production is inversely proportional to the atomic number Z squared. μ pair $= \frac{K}{Z^2}$. This function increases with the voltage.

At 2 M.E.V pair production represents a small fraction, about 3%, of the total absorption coefficient of iron, and a somewhat larger fraction, approximately 10% of the total absorption coefficient of lead.

Pair production is of little consequence in the radiographic problems discussed here, since

the voltage at which it becomes important is much higher. It does limit the useful range of the betatron as an x-ray generator to voltages less than about 30 M.E.V. (Note the rise in absorption coefficient at the higher energies, Figures 20, 21, 22.)

Summary

The three processes which give rise to continuous absorption of x-rays and gamma rays are the photoelectric effect, Compton scattering by free electrons, and pair production. The relative importance of the processes depends on the energy of the incident photon and the atomic number of the absorbing element. For small quantum energies the photoelectric absorption gives the main contribution to the total absorption coefficient. For higher energies Compton scattering becomes important, and finally for very high energies the absorption is entirely due to pair production.

The fact that the absorption due to pair production is proportional to Z^2 and increases with increasing energy, whereas the absorption due Compton scattering is proportional to the number of electrons Z and decreases with increasing energy, has the consequence that the absorption is at a minimum for a certain wave length. This frequency is higher for lighter elements than for heavier elements. Thus, the penetrating power of x-radiation reaches a maximum value between 1.5 and 18 M.E.V., depending on the material. (See Figures 20, 21, 22.) The radiographic and physical consequences of these facts are obviously very important.

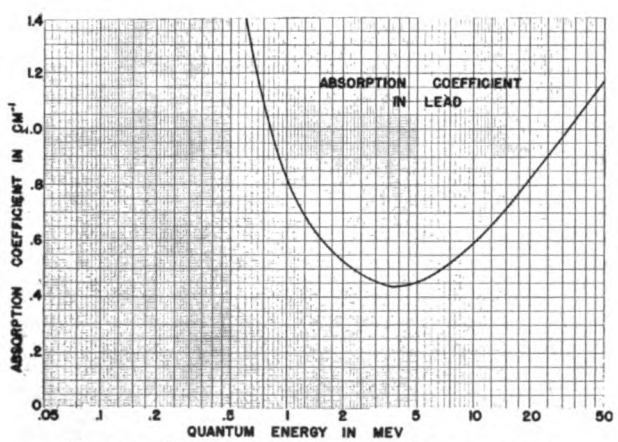


FIGURE 20. Maximum penetrating power of X-radiation in lead

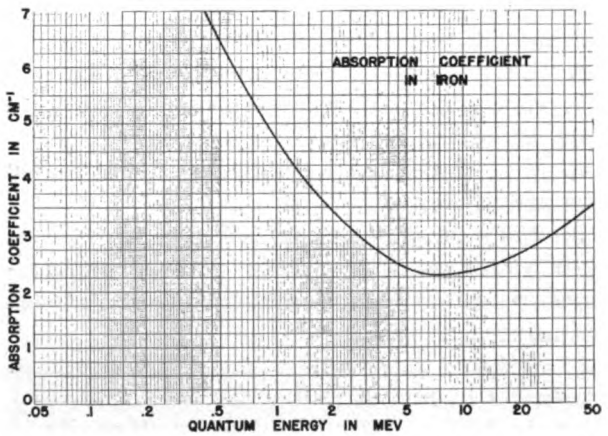


FIGURE 21. Maximum penetrating power of X-radiation in iron

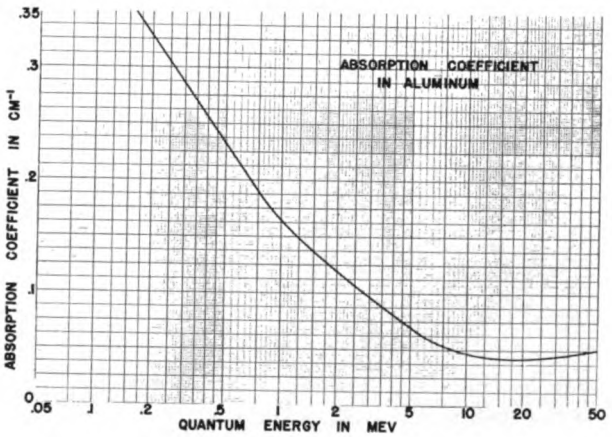


FIGURE 22. Maximum penetrating power of X-radiation in aluminum

The Properties of X-Radiation

Since x-ray and gamma rays are a part of the electro-magnetic spectrum, these radiations can be considered as being similar to other wave bands of the spectrum, such as light, infra-red, and radio.

X-Radiation

1. Is invisible and passes through space without transference of matter.
2. Is propagated in straight lines.
3. Is not affected by electric or magnetic fields.
4. In special cases, is reflected, diffracted, refracted, and polarized just as is light.

5. Is propagated with a velocity of 3×10^{10} centimeters per second as is light.

6. Is transverse electromagnetic vibration.

7. Has wide band of wave lengths, .001 to 1000 Angström units.

8. Is produced by the impact of electrons or ions upon matter.

9. Blackens photographic film.

10. Produces fluorescence and phosphorescence in some substance and colors some stones and minerals.

11. Ionizes gases and changes the electrical properties of liquids and solids.

12. Is differentially absorbed by all media.

13. Liberates photoelectron and recoil electrons in the atomic structure.

14. Is capable of acting photochemically.

15. Is able to damage or kill living cells and to produce genetic mutations.

16. Is produced in a continuous spectrum, with a superimposed line spectrum peculiar to the chemical element of the target.

17. Has an absorption spectrum characteristic of the chemical element.

18. Is diffracted by crystals acting as gratings in accordance with the fundamental law $N\lambda = 2d \sin \Phi$ (See Figure 30).

19. Is found to act in interference and related phenomena as waves but in other phenomena as discrete quanta of energy which may be scattered by single electron.

Chapter 3

EFFECTS AND USES OF X-RADIATION

Film Blackening

In their action on the photographic plate, x-rays seem similar to ordinary light. Since the film absorbs energy from the x-ray beam, the initial process is probably the ionization of the irradiated atoms in the sensitive emulsion. Examination of microscopic sections through the sensitive layer of exposed plates has shown, however, that x-rays, unlike light, produce an equal distribution of grains of reduced silver throughout the whole thickness of the layer. Consequently, a greater blackening of the plate, when exposed to x-rays, can be obtained by increasing the thickness of the sensitive layer and by coating both sides of the base with the sensitive silver bromide emulsion.

This blackening may be used to obtain a photographic record or radiograph which is produced by the passage of x-rays or gamma rays through an object onto a film. Thus, a radiograph is in reality a shadow picture of an object—the dark regions on the film representing the more penetrable parts, and the lighter regions the more opaque.

A much more detailed description of film and film blackening will be given in the next chapter.

Fluorescence

Fluorescence is a phenomenon which depends upon the ability of substances to absorb radiation and transform it into radiation of longer wave lengths in the ultra-violet or visible regions. Energy from the x-ray beam transformed by the substance produces ionization or excitation or both within the atoms of the substance. In returning to their normal states the atoms emit radiation of wave lengths in the visible and ultra-violet range. See Figure 13. Some of these fluorescing substances are calcium tungstate, zinc sulphide, zinc silicate, barium platinocyanide, and others.

A. Sensitivity—Limits of Usefulness

The intensity of fluorescence depends upon the wave lengths of the incident radiation; de Broglie showed that a screen had no intensifying action upon rays with a wave length of 1.25 A.U. but displayed a gradual increase in effectiveness up to the critical absorption wave length of tungsten at about 0.179 A.U. at which point, corresponding to greater absorption, a sharp increase occurred for the shorter wave lengths. For ordinary work the point of maximum efficiency is about 150 KV. Efficiency drops off again at higher voltages.

The response of a fluorescent screen to intensity of radiation is linear. See Figure 23.

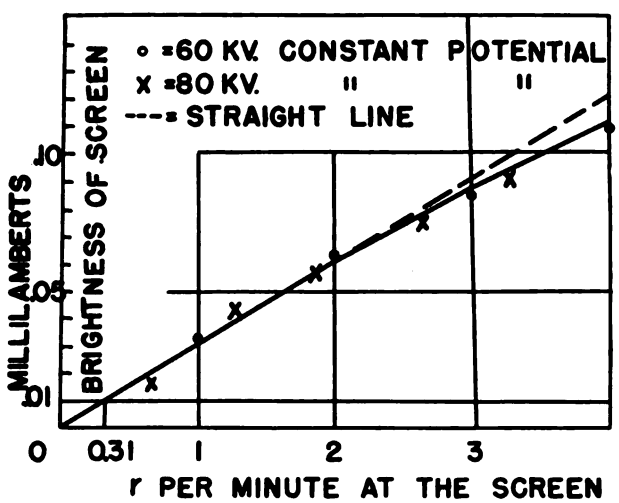


FIGURE 23. Linear response of screen to intensity

In x-ray work, fluorescing screens are made use of in two different ways: (1) calcium tungstate screens which emit radiation of that range to which the film is most sensitive are placed on either side of x-ray film to hasten the action of the x-radiation upon the film; (2) fluorescing screens which emit light of that range to which the eye is sensitive are used in the visual inspection of foods, thin metal sections, fabricated assemblies and in medical work.

For observation of inhomogeneities on the ordinary fluorescent screen a difference in brightness of two adjacent areas of the shadow

must be approximately 15 percent, and a blowhole or gas pocket in aluminum, iron, or copper must be 5 to 7 percent of the total thickness of sound metal for certain conclusions.

Normally, the smallest thickness of flaw or inhomogeneity that can be readily detected by the use of "high-speed" fluorescent screens in combination with screen film is in the order of 2 percent.

The response of film to intensity of light or x-radiation is not linear but logarithmic, as may be seen in the next chapter. Therefore greater sensitivity may be obtained through the use of film than through viewing a fluorescent screen.

B. Photography of Fluorescent Screen

Fluorescent screens may be photographed with a camera and the image recorded on the photographic film. The photographic film when processed is viewed on an enlarging viewer. This system has the advantage of keeping a permanent record with less film cost. The sensitivity is better than that of the fluorescent screen, but not very much better owing to the large size of the screen grains, since the whole grain lights up when a portion of it is struck by a photon.

C. Range of Eye Sensitivity

The light emitted by the fluorescent screen is well within the range of the human eye (see (Figure 24). However, the intensity of light is extremely low in most cases.

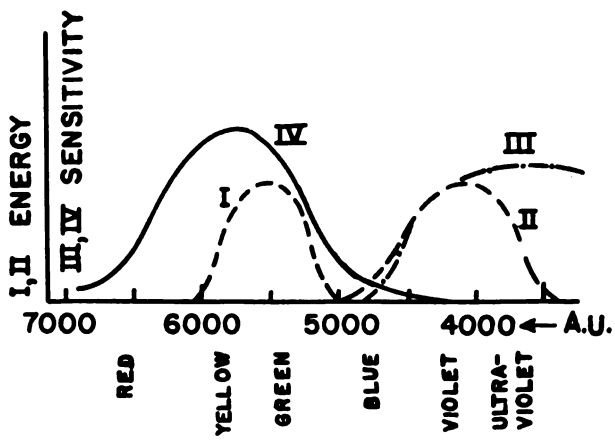


FIGURE 24. Curves showing spectral ranges of maximum sensitivity of the eye and photographic plate, to which should correspond, respectively, the fluorescent screen and the intensifying screen. *I*, Fluorescent screen; *II*, calcium tungstate intensifying screen; *III*, silver bromide of photographic emulsion; *IV*, human eye

D. Eye Accommodation

The eye is able to detect light intensity differences of 1 or 2 percent on a radiograph when placed on a suitable viewer. However, it may require, even after adaptation of the eye to darkness, a difference of 20 to 40 percent for discrimination at the low intensities which are often found in fluoroscopy.

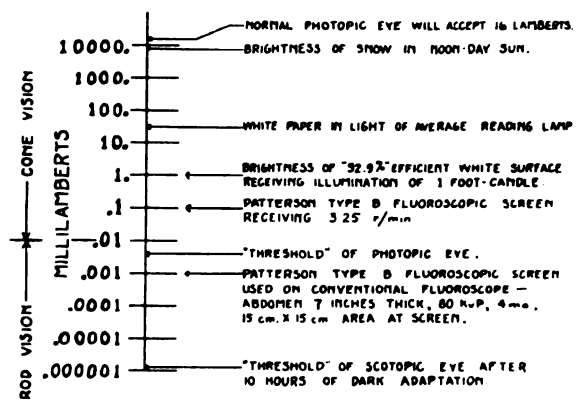

NORMAL PHOTOPIC EYE WILL ACCEPT 16 LAMBERTS.
BRIGHTNESS OF SNOW IN NOON-DAY SUN.
WHITE PAPER IN LIGHT OF AVERAGE READING LAMP
BRIGHTNESS OF "92.9%" EFFICIENT WHITE SURFACE RECEIVING ILLUMINATION OF 1 FOOT-CANDLE
PATTERSON TYPE B FLUOROSCOPIC SCREEN RECEIVING 3.25 r/min
"THRESHOLD" OF PHOTOPIC EYE.
PATTERSON TYPE B FLUOROSCOPIC SCREEN USED ON CONVENTIONAL FLUOROSCOPE — ABDOMEN 7 INCHES THICK, 80 KvP, 4 ma., 15 cm. X 15 cm AREA AT SCREEN.
"THRESHOLD" OF SCOTOPIC EYE AFTER 10 HOURS OF DARK ADAPTATION
CONE VISION
ROD VISION
MILLILAMBERTS
10000.
1000.
100.
10.
1.
.1
.01
.001
.0001
.00001
.000001

FIGURE 25. On the scale is indicated the change-over between rod vision (low brightness levels) and cone vision (high brightness levels) as though it occurred suddenly at 0.01 millilambert. The transition actually takes place more gradually, in the range between 0.01 and 0.1 millilambert. Even in the range between 1.0 and 0.1 millilambert, where cone vision is operative, deterioration in visual acuity and intensity discrimination with lowering of the brightness level, becomes very noticeable

In practice the average intensity of a Type B Patterson screen ranges from .0001 to .01 millilambert. From Figure 25 it will be seen that after the eye has been dark-adapted for 10 or 12 hours, it is able to detect light in the order of one-millionth millilambert. If the eye has been subjected to bright light for several minutes the smallest intensity which the eye will register is about .004 millilambert. The upper region of light energies which the retina, without injury to itself, will transform to cerebral values of vision is in the order of 15,000 millilamberts. In other words, the threshold of a light-conditioned eye is about 4000 times that of completely dark-adapted eye

and the relation of the highest energy acceptable to the lowest distinguishable is about ten billion to one.

From Figure 26 it will be seen that the threshold of cone vision (high intensity) is reached after 3 minutes of dark adaptation. Dark adaptation of rod vision (low intensity) begins

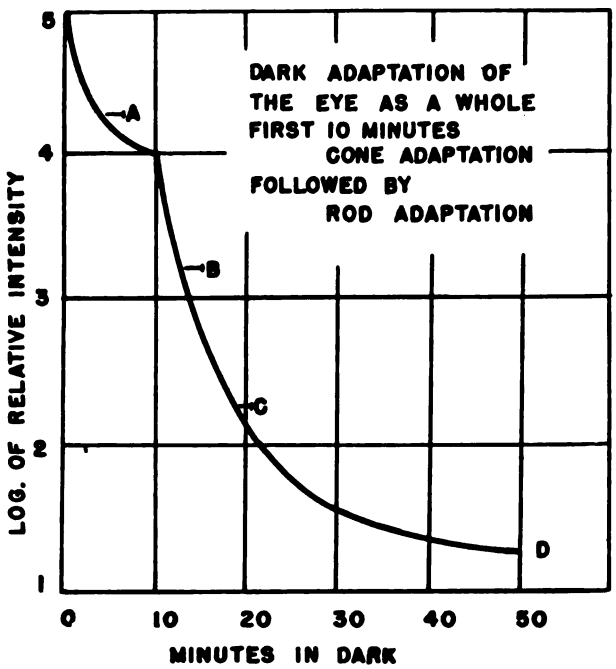


FIGURE 26. Rod and cone adaptation of the eye

to be measurable after 10 minutes, and the major portion of the increase of sensitivity is accomplished in the first 20 to 25 minutes. It has been found that rod vision is not effected by deep red light, so it is possible for the dark adaptation to take place under a light of that color, eliminating the period of inactivity.

A lambert is the C.G.S. unit of brightness equal to the brightness of a surface radiating or reflecting one lumen per centimeter.

The sensory layer of the retina, the layer of rods and cones is almost the outermost layer. Beyond it lie only the pigment granules. It is composed of small rodlike bodies interspersed with shorter conical bodies, both of which are specialized terminal parts of elongated nerve cells. The cones alone are believed to serve in distinguishing colors.

Intensity discrimination, as shown in Figure 27, might be described as the smallest visible difference in light intensities of two adjacent areas expressed as a fraction of the brightness level. For example, at an intensity of .01 millilambert, the smallest visible difference in intensity is 0.1 or 10 percent.

Since intensity discrimination, Figure 27, and visual acuity, Figure 28, are greatly altered by the lower light intensities met with in fluoroscopy, it follows that limitations in fluoroscopic visibility are largely a matter of retinal physi-

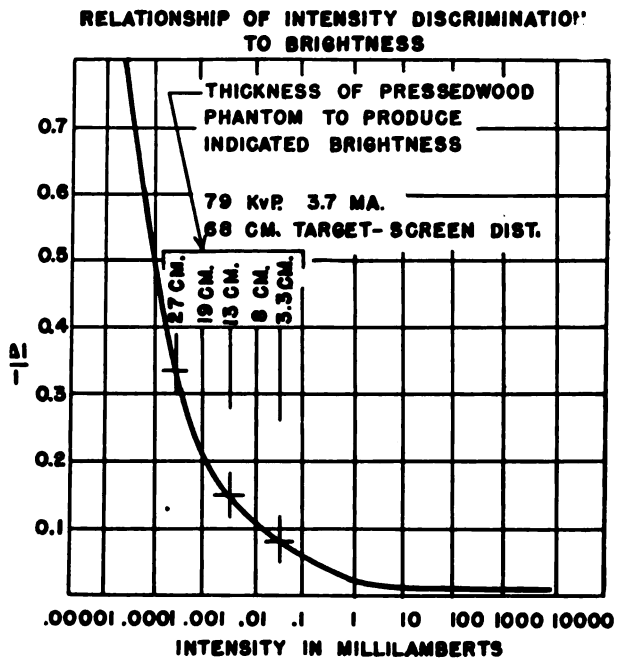


FIGURE 27. Intensity discrimination ($\Delta I/I$) is expressed as the fraction by which a given light intensity must be added to in order for the difference to be visable at that particular brightness level

ology, and brightness level is the most important single factor.

Visual acuity, Figure 28, is defined as the reciprocal of the angular distance which must separate two contours in order that they be visible as being separated, the unit of separation being one minute of arc the radius of which is the viewing distance. For example, at an intensity of .0001 millilambert and 25 inch viewing distance the separation must be .15 inch or more. This was arrived at by finding the reciprocal of the value on the visual acuity scale opposite .0001 on millilambert

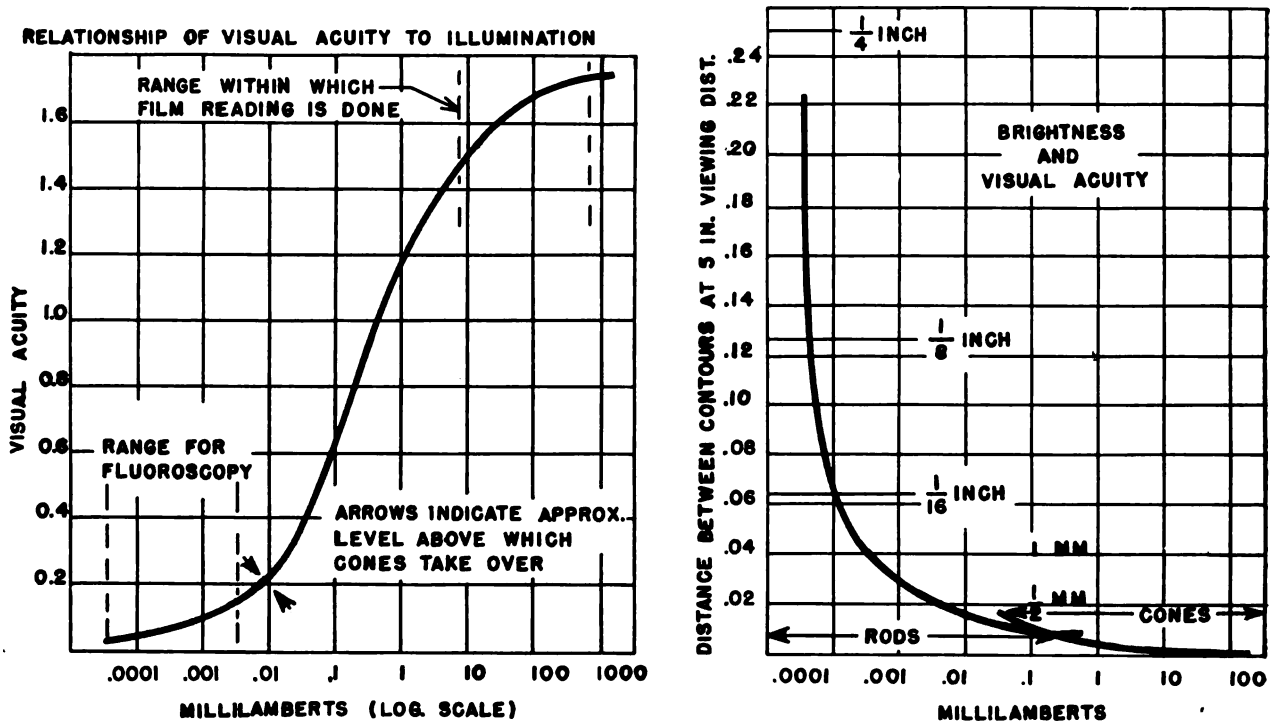


FIGURE 28. Visual acuity is defined as the reciprocal of the angular distance which must separate two contours in order that they may be recognized as discrete, the unit of separation being one minute of arc. The graph on the left is after Hecht, and we have indicated with brackets the approximate ranges of brightness within which film reading and fluoroscopy ordinarily occur. Our indication (arrows) of the boundary between rod vision (low intensity) and cone vision (high intensity) is open to question because the change-over does not occur suddenly and a far more important feature of retinal physiology is indicated by the steepness of the curve in the range between brightness 1.0 and 0.01 millilambert

scale, thus changing it to minutes of arc, which is then converted to distance, .15 inch, on the arc, the radius of which is 25". (Distance $= \frac{\pi}{21600} \times$ minutes of arc $\times$ radius.)

Visual acuity may be increased by viewing with a low power lens, which has an effect of increasing the retinal arc.

Ionization

X-rays and gamma rays eject electrons from the atoms of elements upon which they impinge. The atoms are therefore ionized. This ionization is probably the most important phenomenon among all of the radiation effects discussed in this section. In many cases involving elements in the solid state, the ions and electrons recombine quickly. It is difficult, therefore, to analyze in detail the processes that produce the observed effect. However, when gases are ionized by either x-rays or gamma rays, the ionization may be more directly apparent.

When a beam of x-rays or gamma rays passes through a gas, the energy absorbed by the gas is initially transformed chiefly into (1) increased potential energy of ionized atoms and (2) kinetic energy of photoelectrons and recoil electrons. The increased potential energy of the ionized atoms may be transformed subsequently into the characteristic raditation of these atoms.

The kinetic energy of the photoelectrons and recoil electrons is expended in the production of ionization by collision. These ions, in turn, may recombine to produce characteristic radiation. If such characteristic radiation leaves the volume of the gas under consideration, it is not a part of the energy absorbed. On the other hand, if quanta of such characteristic radiation interact within the volume with the atoms, they produce more ions. Finally, low-speed electrons or low-energy quanta may produce heat.

The number of ion-pairs produced in air by photoelectrons and recoil electrons is several

hundred times as large as the number of photoelectrons and recoil electrons produced by quanta of the incident radiation. The method of measuring the energy absorbed from a beam of radiation passing through air is based upon three facts: (1) the radiation produces a few ions and high-speed electrons, (2) the high-speed electrons subsequently produce many ions, and (3) the average energy to produce an ion-pair can be accurately measured. Therefore, if the process of absorption can be interrupted before any ions recombine, and all of the ion-pairs "counted," the initially absorbed energy can be calculated by multiplying the number of ion-pairs produced by the average energy required to produce each ion-pair. This is the process used to measure dose and dose-rate by means of free-air ionization chambers, the ions produced in a volume of air are prevented from recombining by placing two oppositely charged plates near the volume. The ion-pairs are "counted" by measuring the electric charge collected by one of the plates.

Upon this basis, the International Committee for Radiological Units in 1937 defined the unit of dose of x-ray or gamma rays. The unit of dose is called the *roentgen* and is designated by the symbol *r*. The definition is: "the roentgen shall be the quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces in air ions carrying 1 esu of quantity of electricity of either sign." The specified mass 0.001293 gram is the mass of 1 cc. of dry atmospheric air at 0°C. and 760 cm. of mercury pressure. "Corpuscular emission" comprises photoelectrons and recoil electrons. (The electrostatic unit of charge (esu) is equivalent to $\frac{1}{3} \times 10^{-9}$ coulomb.) The unit of radiation dose rate is the *roentgen per minute.*

Therapy

It has been shown by experiments that x-rays and gamma rays produce changes in certain biological materials. The theory of these changes is far from complete. It is probable that the initial effects that lead ultimately to these changes is the ionization of the atoms of the irradiated material by the energy absorbed from the radiation. The subsequent effects have not been satisfactorily correlated.

In the field of roentgen therapy the gross effects of the biological changes are utilized. Many of the reactions of living tissue to irradiation by x-rays and gamma rays have been empirically determined and it is assumed that the intensity of the reactions depends upon the amount of energy absorbed and its rate of absorption by the tissue regardless of the wave length of the radiation. The amount of radiant energy absorbed by the tissue depends upon the dose and quality of the radiation incident upon the tissue. X-ray therapy has been used beneficially to produce the following effects: (1) inhibition of the growth or function of glands and cells, such as the treatment of certain skin diseases, (2) destruction of fungi, (3) reduction of certain inflammations, such as carbuncles, pneumonia in certain stages, erysipelas, etc., (4) treatment of gas gangrene infections, and (5) destruction of malignant tumors, or cancer.

Diffraction

In an element, each atom possesses exactly the same electrical affinity for every other one. Consequently, the atoms have a *definite* arrangement in 3-dimensional space. The atoms in copper, for instance, are arranged (as in Figure 29) in a unit cell which is repeated throughout the structure. The atoms at the top of the unit form the bottom of the cell above, and so on in all directions.

X-ray diffraction is the science that enables us to measure the spaces between the planes of atoms or groups, in such a unit cell, and from the information thus obtained identify the material, no matter how complex the lattice may be. This is because the extremely short wave lengths of the x-rays are of the same order as the spacings between the planes of atoms or particles in crystalline structures. These distances are extremely small, usually varying between 0.7 and 1000 Angströms. In diffraction x-ray work, target x-ray tubes giving the characteristic radiation of molybdenum, copper, cobalt iron, and chromium are used. These give a wave length range between 0.709 and 2.28 Angströms.

As shown in Figure 30 these waves penetrate into the outer layers of the material being examined. Some are reflected from the top layer; others from the second, and so on. Rays reflected from a point on the material examined may be coming from different depths in the

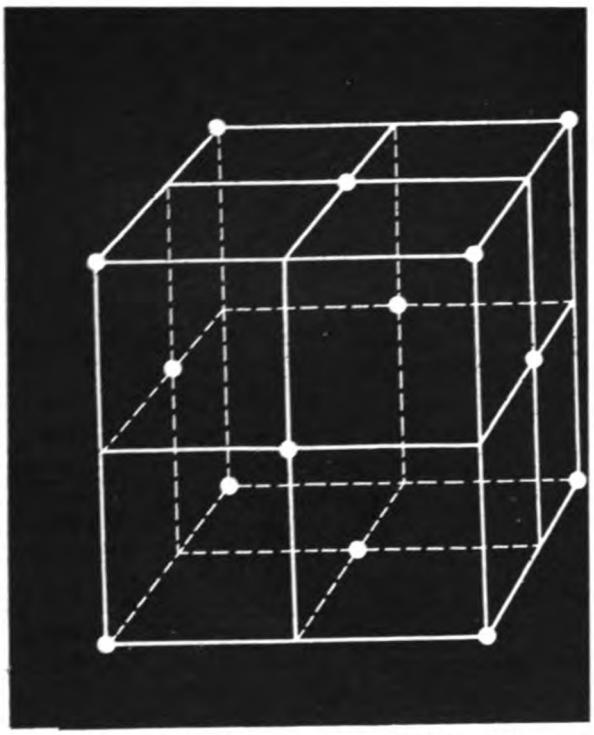


FIGURE 29. Atomic structure of copper

material. If these rays are allowed to fall on a fluorescent screen or a photographic negative, various figures, known as diffraction patterns are obtained. For example, let us think of a point on the screen where the waves reflected from the second layer arrive exactly one-half wave length later than those from the first layer. The crest of one wave then coincides with the trough of the next, and the two cancel each other. At some other point on the screen or film, the waves from the second or some other layer of the crystalline substance may arrive exactly one wave length behind those from the first. The result is that they reinforce one another, and the impact on the sensitive surface is doubled. Thus dark and light areas are formed. Their distance apart is governed by the angle of the ray, the wave length of the particular x-rays used and the

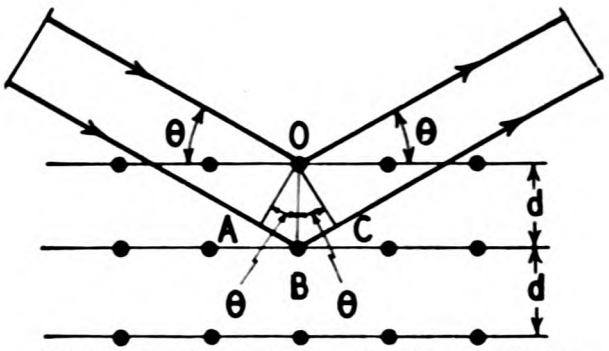


FIGURE 30. Atomic layers reflecting x-radiation

spacings between the atomic planes in the material. Knowing two factors, the other may be determined simply by the use of the relation:

$$n\lambda = 2d \text{ sine } \Theta$$

known as Bragg's Law, in which n equals any integer, λ equals the wave length, d equals the spacing between atomic planes, and Θ equals the angle made by the incident beam and crystal face, also the angle between the reflected beam and crystal face. Figure 30 represents a cross section of the crystal showing the assumed distribution of atoms parallel to the crystal face. Two incident rays are shown, one being "reflected" from the atom at O and the other from the atom at B. These reflections are produced by unmodified scattering and they actually occur in all directions from the atoms. It happens, however, that the intensity of the "reflected" beam is greatly reduced in most directions by partial or complete interference. As is shown in the figure the lower beam travels farther than the upper beam by the distance ABC. The two beams reinforce one another only if the difference in length of the two paths is equal to an integral multiple of the wave length. The distance AB equals distance BC and each equals d sine. The difference in path lengths is therefore $2d$ sine Θ which must equal $n\lambda$.

For the purposes of x-ray analysis by the powder method, very small quantities of material are required. One-tenth of a milligram is adequate for complete identification. The substance to be analyzed is placed inside a fine capillary tube about $\frac{3}{10}$ of a millimeter in diameter. This is mounted vertically at the center of a ring of x-ray film held inside the metal body of the camera shown in Figure 31.

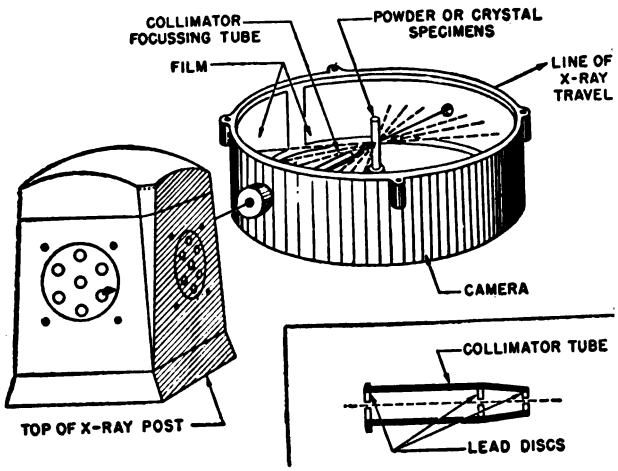


FIGURE 31. Diagram of an x-ray diffraction unit

FIGURE 32. Sample diffraction film strip. White lines are points of high intensity. The angles at which these occur with respect to the beam are simply calculated. Then knowing wave length and angles, interatomic spacing, d is calcuted from Bragg's Law $n\lambda = 2d$ sine Θ

A fine pencil of x-rays, about ½ mm. in diameter is permitted to strike the specimen, which is rotated at low speed by a small motor. "Cones of interference and reinforcement" are radiated from the specimen sections struck by the rays. These cones then strike the film in concentric lines around the central beam. The film is then developed and the angle between the diffracted cones and main beam measured. The interatomic spacings of the specimen can readily be determined by these measurements.

Another system for x-ray analysis is the Geiger Counter Spectrometer in which the film is replaced by a Geiger Counter tube mounted on a vernier reading arc. The tube is connected to an amplifier and meters, so that as it is rotated through the arc the meter readings indicate the average intensity of the reflected radiation at any point on the arc and the actual number of pulses from a stepping counter. From these measurements the atomic spacings may be determined and materials analyzed qualitatively and quantitatively.

Microradiography

This is a relatively new field but founded on the same basic principle of all radiography, the differential absorption of x-rays, $I = Io\ e^{-\mu x}$. The outstanding differences are that the objects or specimens are only a few thousandths of an inch thick, and that the radiographs are made on fine grain film and enlarged as much as 300 times. It is widely used to supplement the information obtainable from photomicrography especially in metallurgy.

Since the specimen is thin and maximum contrast is desired, very low voltages are used. However, x-ray absorption by matter at the longer wave lengths is complicated by the critical absorption wave lengths.

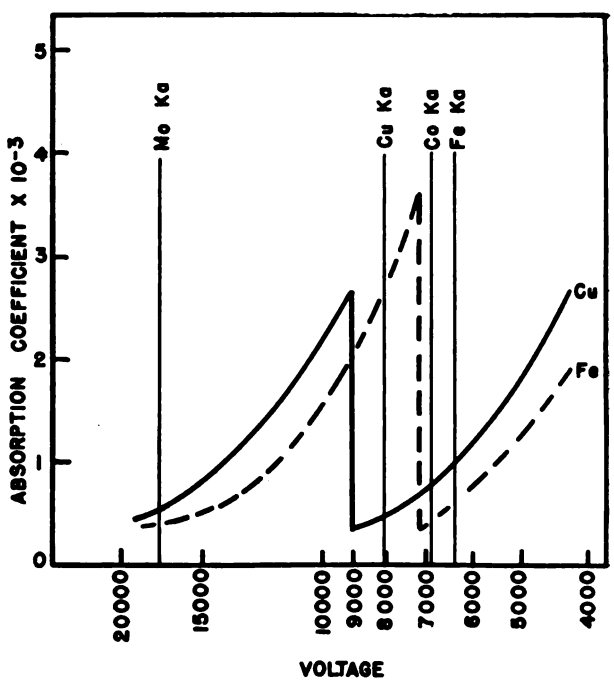


FIGURE 33. Absorption of copper and iron between 4 and 20 KV

Figure 33 indicates the abrupt changes in absorption of iron and copper in the range of 6 to 10 KV. It is plain from these curves that at 20 KV copper and iron have approximately the same coefficient of absorption and hence would be indistinguishable on a radiograph. At 7.2

KV, however, there is a great difference in their coefficients of absorption; this difference would be apparent in a radiograph.

White or unfiltered tungsten radiation at low voltages is very weak in intensity. When different metals of lower atomic number than tungsten are used as x-ray targets they produce characteristic radiation of longer wave length which is quite intense. By the use of proper filters it is possible to eliminate most of the white or background radiation if desired, but this is not usually necessary.

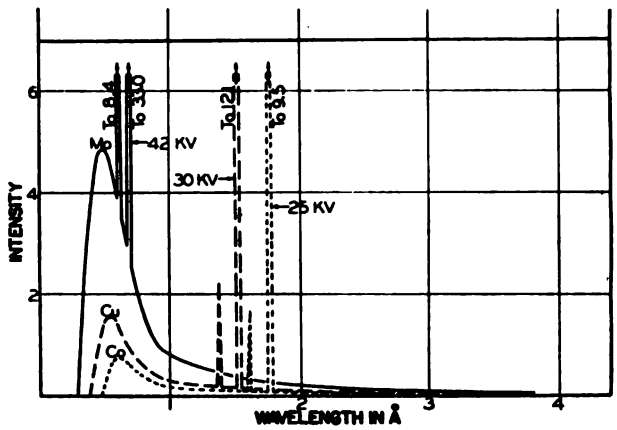


FIGURE 34. Linear absorption differential between iron and copper as function of wave length correlated with x-ray emission curves of molybdenum at 40 KV, copper at 30 KV, and cobalt at 25 KV

Figure 34 indicates the relative intensities of this characteristic radiation for different targets. Figure 33 indicates the relation of the target radiation to the relative absorption coefficients of the specimen. A target is selected which will produce maximum intensity radiation of a wave length where the difference in absorption coefficients is greatest.

The characteristic wave lengths for different targets may be obtained from Compton and Allison tables. An absorption plot may be obtained from the absorption tables in the Handbook of Chemistry and Physics.

When two or more elements are in solid solution or combination, the linear absorption coefficient may be calculated from:

$$\mu = d\left(\frac{Xpx + Ypy}{X + Y}\right)$$

d = density of combination
X, Y = elements by weight
px, py = mass absorption coefficient

Chapter 4

X-RAY FILM

General

X-ray film for general radiography consists of a blue-tinted, cellulose acetate base, coated on both sides with a sensitive emulsion. The emulsion is about one-thousandth inch thick and consists of gelatin in which are suspended grains of silver bromide, iodide, and/or chloride collectively called silver halides. See Figure 35.

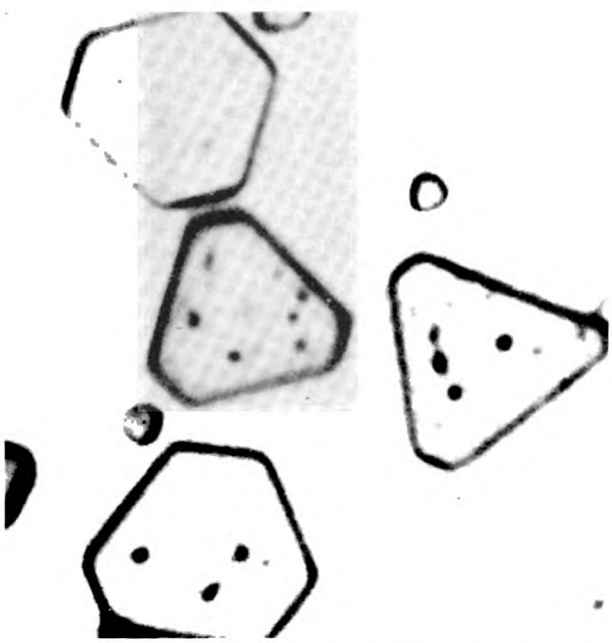


FIGURE 35. Photomicrograph of silver halide grains from a photographic emulsion. X8,000. Black spots correspond to development centers

Exactly what happens when x-rays strike a film is not completely understood. It is assumed that electrons scattered from the film and lead screens (and ultra-violet and visible light in the case of calcium tungstate screens) strike some of the halide crystals and create "development centers." These are tiny specks of metallic silver (estimated 2500 atoms) within the crystal. When the film is developed this "latent image" becomes visible because the whole crystal is reduced to metallic silver. Even an unexposed film will upon development contain some silver, resulting in what is known as "base fog density."

Density

Hurter and Driffield, pioneer workers in sensitometry, defined density as the logarithm to the base ten of the reciprocal of the transmission, $D = \log_{10} \frac{1}{T}$ where $T = \frac{\text{Transmitted Light}}{\text{Incident Light}}$. Therefore, if a film transmits 10 units of light when 1000 units are incident upon it, it is said to have a density of 2. $D = \log_{10} \frac{1}{\frac{10}{1000}} = \log_{10} \frac{1000}{10} = \log_{10} 100 = 2$ (since $10^2 = 100$).

H and D Curves

In 1890, Hurter and Driffield published a paper in which they described a method of measuring the sensitivity of film to exposure. They plotted film density against the logarithm of exposure. This type of curve is widely used and is illustrated in the accompanying film data. When semi-logarithm paper is used it may be plotted directly from laboratory data. The straight line portion of the curve is generally called the region of correct exposure because the density is directly proportional to the logarithm of exposure; the lower portion is called the toe or region of under-exposure and the shoulder or upper portion, the region of over-exposure. In radiography, however, the shape of the curve, though important, is not the deciding factor. The straight line portion may lie between a density of 3 and 6. A common viewer furnishes light enough to view as high as a density of only 3. Again, laboratory experience has shown that below a density of 1 a film is relatively uninformative. There-

699810—46—3

fore, a correct exposure for an ordinary viewer should furnish a density variation between 1 and 3.

Gamma or Emulsion Contrast

The slope of the straight line portion of the curve is called gamma and is a measure of emulsion contrast.

Gamma $= \frac{D_2 - D_1}{\log_{10} E_2 - \log_{10} E_1}$. Gamma is a characteristic of the manufactured film but its value can be altered somewhat by processing and processing conditions.

Latitude

The range of object thickness or the range of intensities of radiation capable of being recorded by a film is called emulsion latitude. The higher the emulsion contrast or gamma, the smaller the latitude, and vice versa. Since latitude varies inversely with gamma it may be expressed: $L = \frac{1}{\text{Gamma}} \times$ constant. There are many other ways of expressing latitude. (M.I.T. defines radiographic latitude as the ratio of the exposure for a density of 2.5 to the exposure for a density of .3, both taken over and above fog density.) Since Eastman Type F film has the greatest latitude of any film commonly used in the laboratory, it is convenient to consider its latitude as equal to 100. The latitude of other films is then a number relative to 100.

Speed

The speed of film varies generally with the size of the silver halide particles in the emulsion. However, this is an impractical measurement for the radiographer. On the H and D curve if the straight line portion of the curve is projected downward it meets the axis at a point called the *inertia point.* The faster the film, the nearer to the origin this point falls. For developers containing no bromide restrainer this point remains constant for varied development times. Hurter and Driffield multiplied the reciprocal of the inertia (in exposure, not $\log_{10}$ exposure) by 34 to obtain a value for speed. It is customary to take Eastman Type K film as having a speed of 100 and to figure other film speeds from the constant so obtained. $S = \frac{1}{\text{inertia exposure}} \times$ constant. Therefore, constant = 100 × Type K inertia exposure. This type of speed factor is called H and D speed.

The H and D speed factor is not always useful because it is based on a theoretical line of projection. A relative value for speed, unlike latitude is often needed in the laboratory when it becomes necessary, for one reason or another, to change to another type of film. Therefore, an accurate practical speed factor should be available.

It has been found through experience that for routine work a density of 1.5 on the radiograph through the thicker sections is most desirable. Sensitivity falls off abruptly below a density of 1, so .5 density is a desirable margin in radiographic calculation.

For a particular generator if *the exposure times required to produce a density of 1.5 on each type film are considered as relative numbers* it is then practical, within ordinary limits of error, to obtain this critical density on any film having once established the correct exposure time for any one film. (Correct exposure is obtained from film curve, technique chart or previous object.) Type K is arbitrarily considered as having a speed of 100 and the rest are determined accordingly by $S = \frac{1}{E} \times$ constant.

In the laboratory sometimes instead of a film speed factor, an exposure factor is used. These are obviously reciprocals since the faster the film, the shorter the exposure. Exposure Factor $= E \times$ constant.

Base Fog

If x-ray film is processed without having been exposed, it will possess an inherent density. This base fog density will vary with the type of film and with time of development. It is also dependent on film handling in manufacture, conditions of film storage, film age, and type and condition of developer. Figure 41 indicates the base fog variation with developer and type film. Sometimes sensitivity curves are plotted

corrected for base fog, the $D - D_0$ where D_0 = base fog. Since there is no base fog at maximum density, this is inexact. Wilsey's formula gives a better approximation. Fog Deduction = Base Fog

$$\left(\frac{\text{Max. density of film} - \text{density considered}}{\text{Max. density} - \text{Base fog}}\right)$$

Recent work, however, indicates that the effect of base fog on x-ray exposures is additive at all densities and that $D - D_0$ is an exact statement of exposure.

Reversal or Solarization

Some films, particularly EK Type F once they reach the straight line portion of the H and D curve do not continue in a straight line but curve over to the right (see Figure 42) and if exposure is continued, assume a downward slope. The reason for this behavior is not understood.

Advantage of this peculiarity may be taken to copy radiographs. A short exposure (fluorescent viewer — 5 min.) printed through a radiograph on an unexposed sheet of F film normally developed will produce a copy of the original radiograph. However, the quality of the copy is somewhat inferior to that of the original.

Grain Size

After the silver halide has been reduced to metallic silver by the developer and the film is fixed, washed, dried, and examined under a microscope, it is possible to see the actual silver particles. These particles vary in size from a small fraction of a micron (micron = .00003937″) to several microns. All the particles are not the same size but in general follow a normal curve distribution of sizes. The median particle size is fairly definite for any particular brand of film. The smallest grain size for general purpose x-ray film is found in M, the largest in F.

	Approximate Size	
Type Film	Inches	Microns
M	.000031	.8
A	.000063	1.6
K	.000125	3.2
F	.000187	4.8

There is a general correlation between film speed and grain size. As far as can be determined, grain size is controlled only by the manufacturer; it is independent of manner of type of exposure and development.

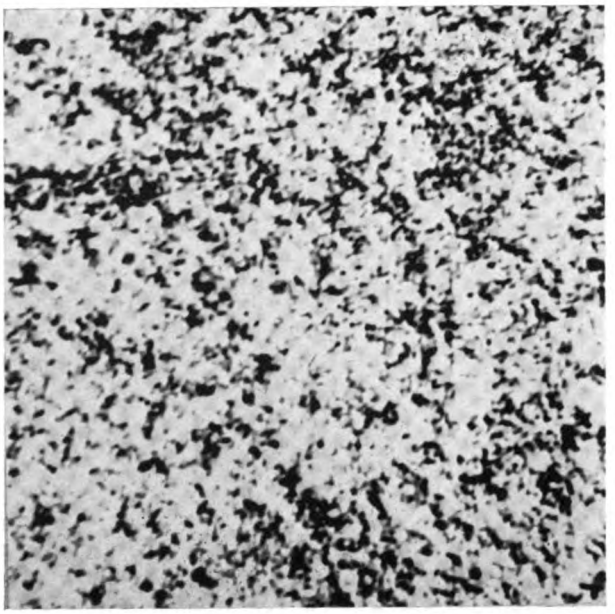


Figure 36. Photomicrograph of Eastman Kodak Type M Film. Exposed in plain holder at 20 KV to a density less than 1, × 500

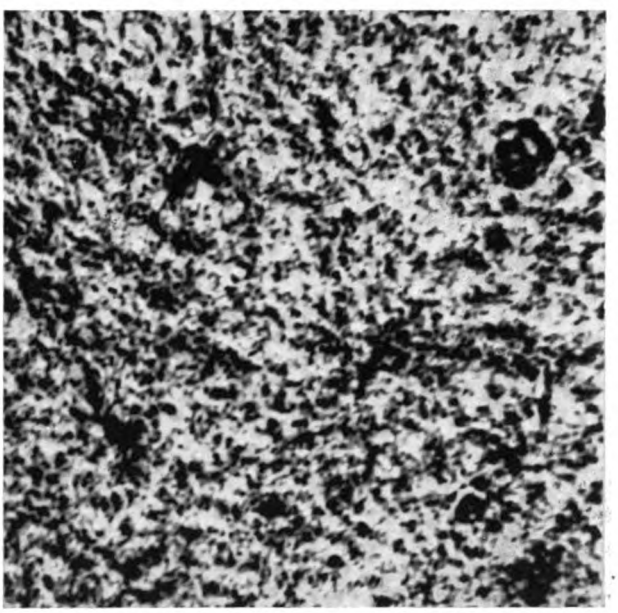


Figure 37. Photomicrograph of Eastman Type M Film. Exposed in lead holders at 2 MEV to a density less than 1, × 500

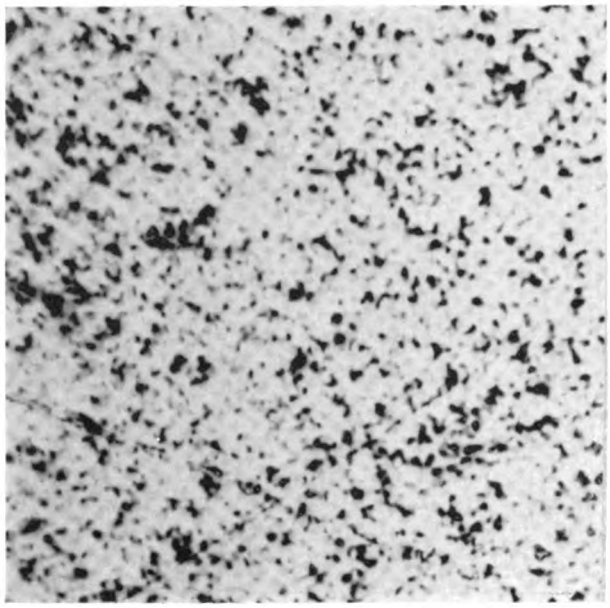


FIGURE 38. Photomicrograph of Eastman Type A Film. Exposed in lead holders at 2 MEV to a density less than 1, × 500

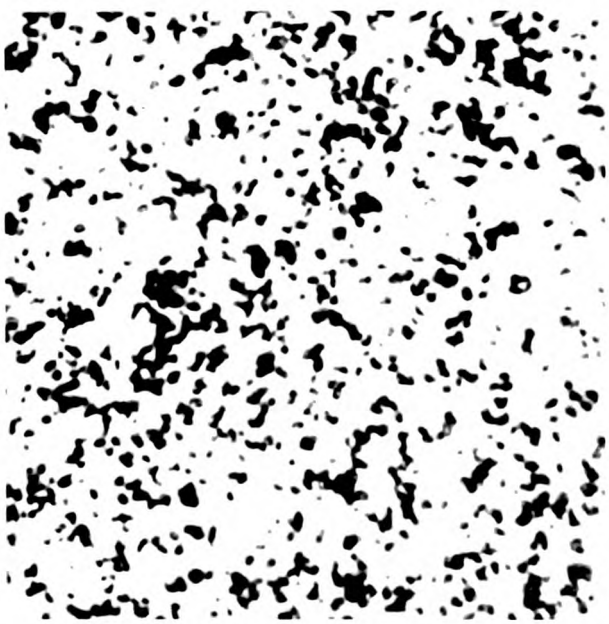


FIGURE 39. Photomicrograph of Eastman Type K Film. Exposed in lead holders at 150 KV to a density less than 1, × 500

Graininess

Clumping together of grains and distortion of the gelatin surface superimposing silver particles is called graininess. It may be caused by hot or highly alkaline developer, high density on the film, long exposure to weak radiation (especially photographic printing paper), overdevelopment, in short, by any increase in gamma. Warm humid storage is a direct cause. Graininess is most apparent (not greater) at a density of .5. At that point the area between grains equals the area of the grains themselves. The same principle of visibility applies to the black and white stripes on highway or railway obstacles.

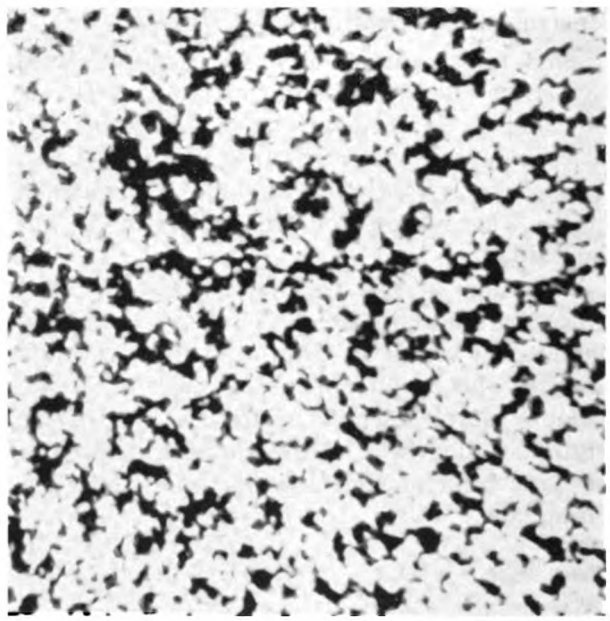


FIGURE 40. Photomicrograph of Eastman Type F Film. Exposed in a lead holder at 2 MEV to a density less than 1, × 500

Characteristic Curves

The accompanying curves and data (Table I) furnish a fairly complete study of the characteristics of the x-ray films in use at the laboratory. No attempt has been made to obtain maximum gamma. The curves represent at closely as possible the normal working curve for each film.

Density versus Exposure

Figure 41 is a sensitrometric curve in which density is plotted directly against exposure instead of $\log_{10}$ exposure. Note the shapes of the curves. For some films density is directly pro-

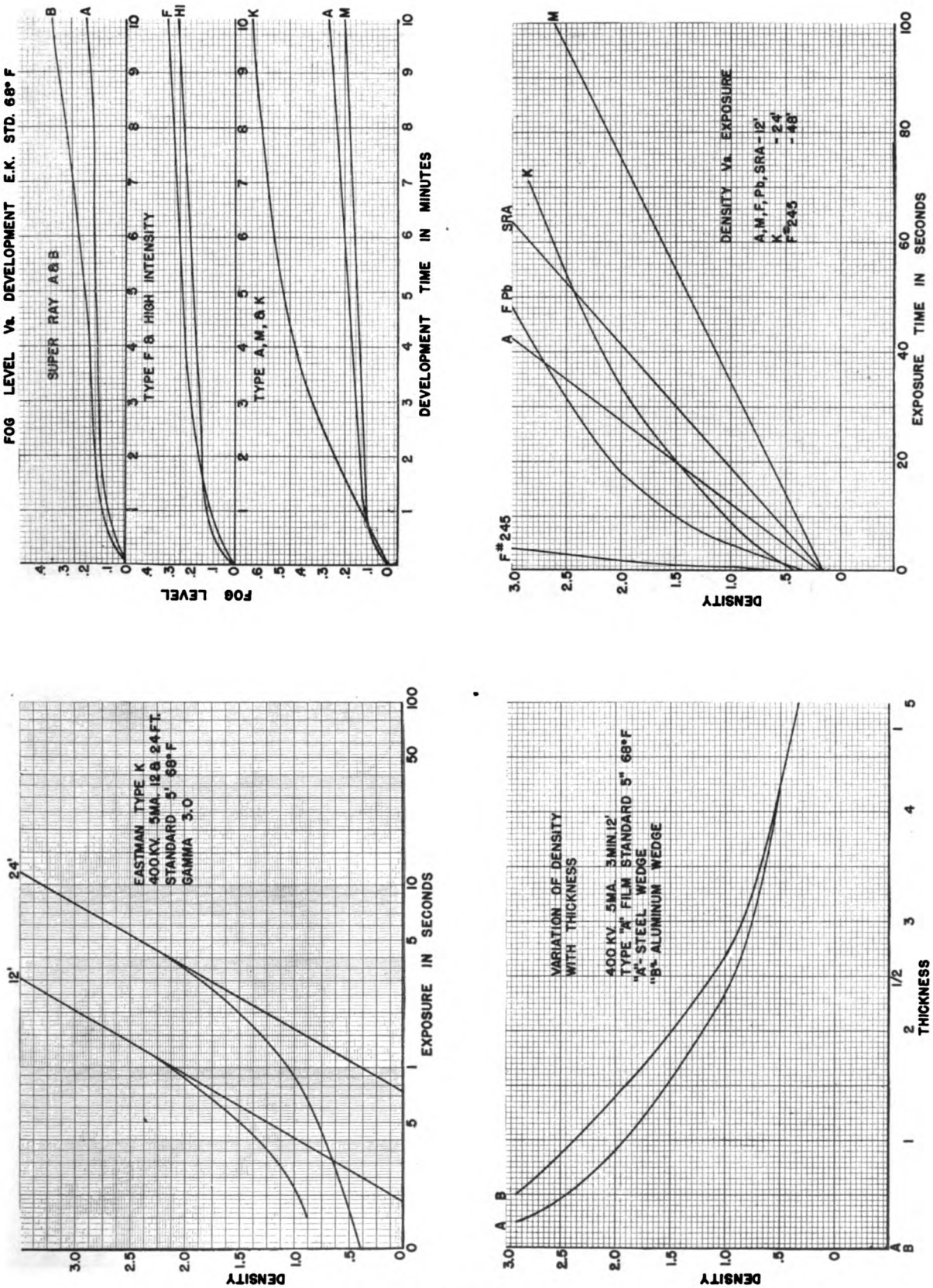

FOG LEVEL Vs. DEVELOPMENT E.K. STD. 68° F
SUPER RAY A & B
TYPE F & HIGH INTENSITY
TYPE A, M, & K
FOG LEVEL
DEVELOPMENT TIME IN MINUTES
DENSITY Vs. EXPOSURE
A, M, F, Pb, SRA - 12'
- 24'
K
F**245
- 48'
DENSITY
EXPOSURE TIME IN SECONDS
EASTMAN TYPE K
400 KV. 5MA. 12 & 24 FT.
STANDARD 5' 68° F
GAMMA 3.0
DENSITY
EXPOSURE IN SECONDS
VARIATION OF DENSITY
WITH THICKNESS
400 KV. 5MA. 3MIN. 12'
TYPE "A" FILM STANDARD 5" 68°F
"A"- STEEL WEDGE
"B"- ALUMINUM WEDGE
DENSITY
THICKNESS

FIGURE 41

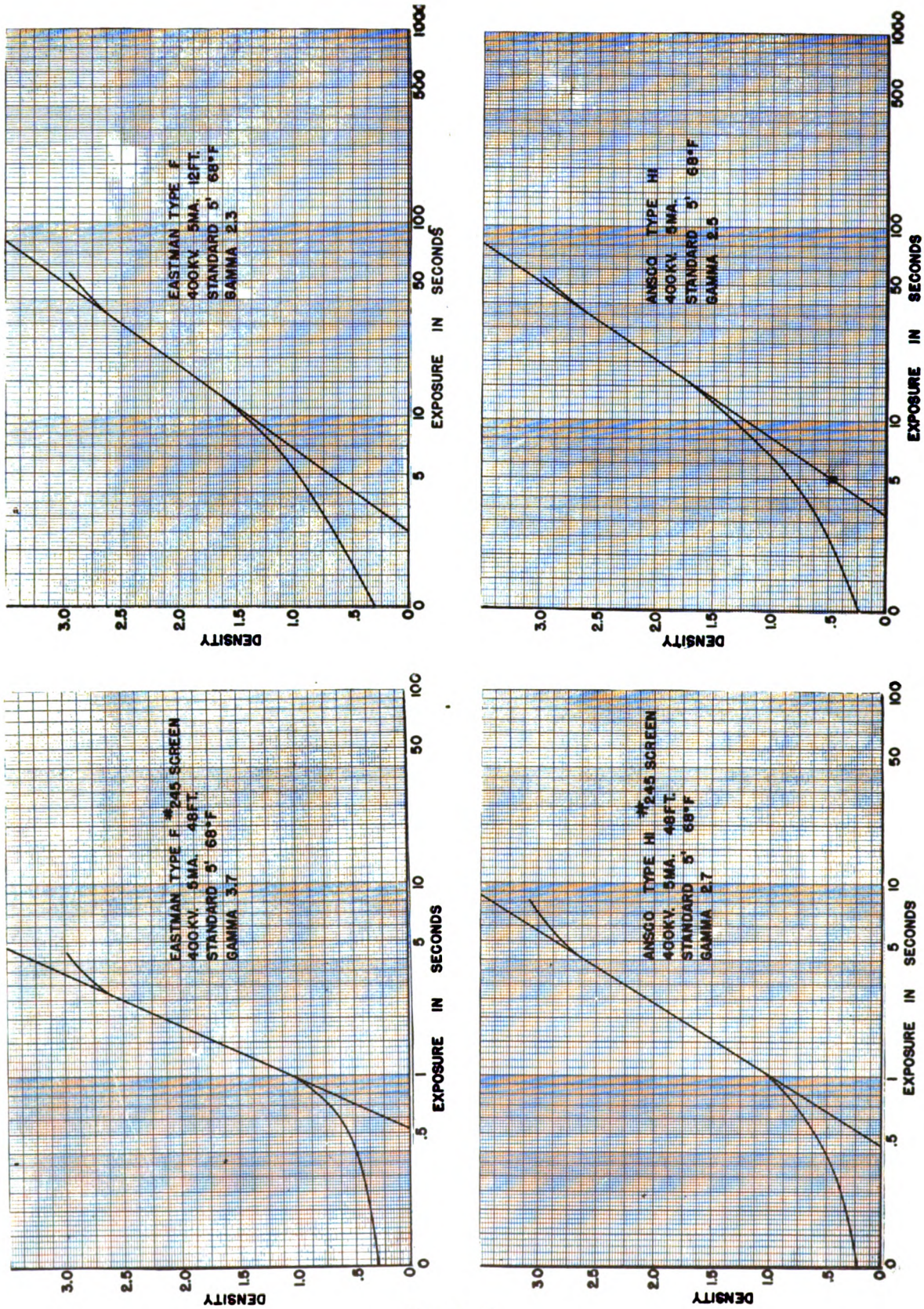

EASTMAN TYPE F
400 KV. 5MA. 12FT.
STANDARD 5' 68°F
GAMMA 2.3
ANSCO TYPE HI
400 KV. 5MA.
STANDARD 5' 68°F
GAMMA 2.5
EASTMAN TYPE F *245 SCREEN
400 KV. 5MA. 48FT.
STANDARD 5' 68°F
GAMMA 3.7
ANSCO TYPE HI *245 SCREEN
400 KV. 5MA. 48FT.
STANDARD 5' 68°F
GAMMA 2.7
DENSITY
EXPOSURE IN SECONDS

FIGURE 42

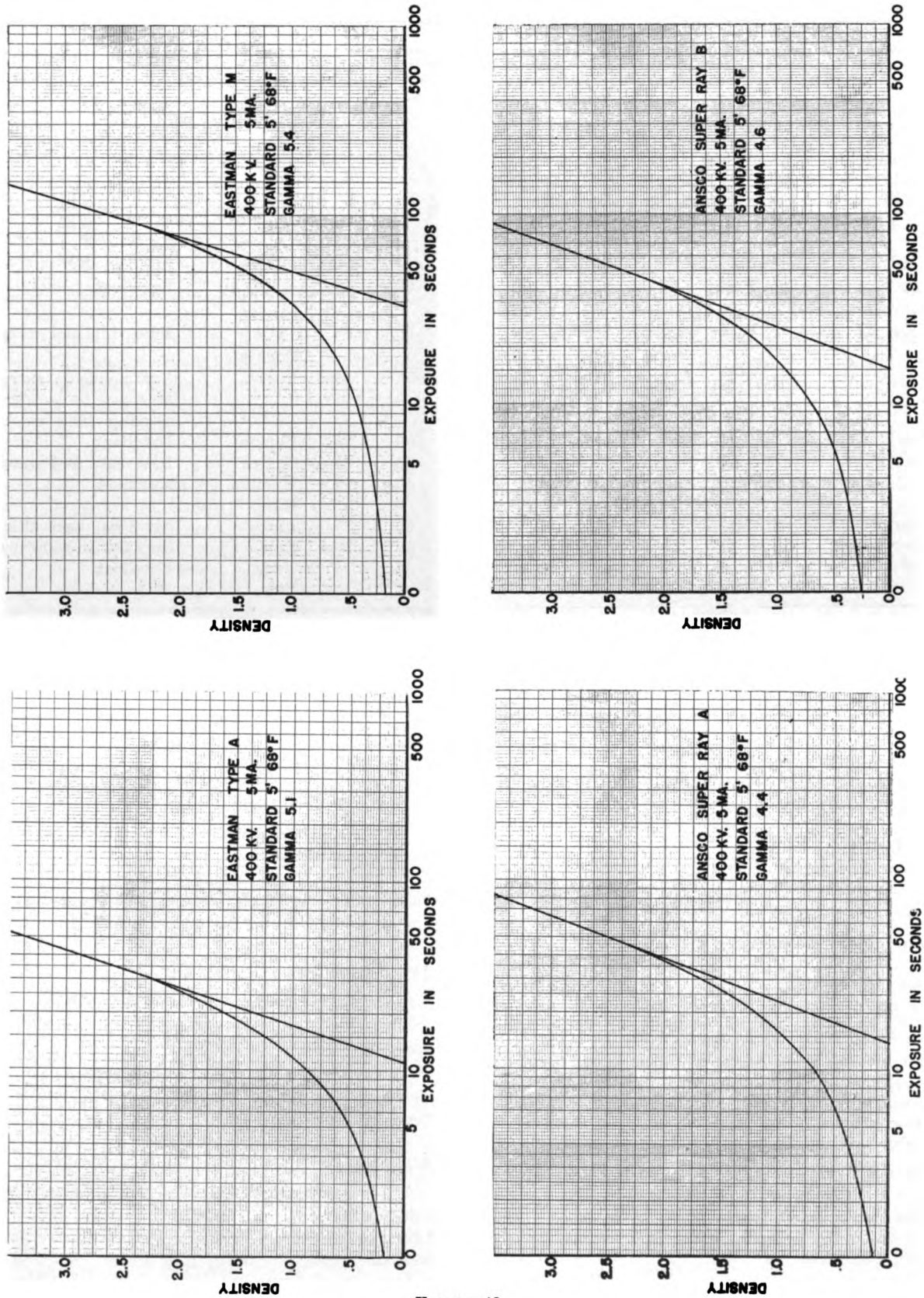

EASTMAN TYPE M
400 KV. 5 MA.
STANDARD 5' 68°F
GAMMA 5.4
ANSCO SUPER RAY B
400 KV. 5 MA.
STANDARD 5' 68°F
GAMMA 4.6
EASTMAN TYPE A
400 KV. 5 MA.
STANDARD 5' 68°F
GAMMA 5.1
ANSCO SUPER RAY A
400 KV. 5 MA.
STANDARD 5' 68°F
GAMMA 4.4
DENSITY
EXPOSURE IN SECONDS

FIGURE 43

TABLE I

Data from Curves at 400 KV 5 ma 12' Standard 5' @ 68°F. Lead Screens Unless Noted	*OIL Speed* $\frac{500}{E}$	*Density 1.5. Exposure in Seconds 400 KV 5ma 12'*	*H & D Speed* $\frac{185}{I}$	*Inertia in Seconds*	*Gamma*	*Latitude* $\frac{230}{\gamma}$	*Fog Density*	*Grain Size*	*Physicial Qualities*
Type F #245	6000	.084	5700	.52 $\frac{}{16}$	3.7	62	.25	Very Coarse	Excellent
Ansco HI #245	5230	.096	7000	.42 $\frac{}{16}$	2.7	85	.20	Very Coarse	Base thin and wavy
Type K	100	5.	100	1.85	3.0	77	.48	Coarse	Soft emulsion extremely sensitive to handling; requires long wash
Type F	46	11	74	2.5	2.3	100	.25	Coarse	Excellent
Ansco HI	41	12	58	3.2	2.5	92	.20	Coarse	Base thin and wavy
A	26	19	16.8	11	5.1	45	.19	Medium Fine	Excellent
Super Ray A	18.5	27	14	13.7	4.4	52	.15	Fine	Emulsion base thin
Super Ray B	17	29	12	15.5	4.6	50	.20	Fine	Buckles; dries wavy
Type M	9	55	5.6	33	5.4	43	.14	Very Fine	Excellent

TABLE II

Film Uses

Eastman Type A
General purpose
Standard film
Medium fine grain
Medium speed

Eastman Type M
For objects requiring great detail and high sensitivity.
Slow, high contrast
Fine grain

Eastman Type F (lead screens)
For dense objects where a higher kilovoltage is not available.
Medium speed
Coarse grain
Greater latitude, low contrast

Eastman Type F (calcium tungstate screens)
For radium work and extremely thick or dense objects on Van de Graaff
Very fast
Medium contrast
Very coarse grain

Eastman Type K
For estimating exposures on new objects particularly for Van de Graaff.
Fast, medium contrast, very coarse grain
Thick emulsion, extremely sensitive to pressure marks
Requires long washing period (30 minutes)

Ansco High Speed
A fairly satisfactory substitute for type F.

Super Ray A
A less satisfactory substitute for type A.
Slower
Poor emulsion base

Super Ray B
A less satisfactory substitute for type M. Almost twice as fast.
Larger grain
It is most similar to Super Ray A
Poor emulsion base

portional to exposure; slope is an approximation of speed. These can be very useful in deriving the correct exposure time for an unfamiliar object. For instance if at 400 KV at any distance the first trial shot for 9 minutes on M film proved to be exposed to a density of 1.0 where a density of 1.5 is desired, take from the curve the ratio of exposures for these densities and multiply by the original exposure. Thus $\frac{56}{36} \times 9 = 14$ minutes under the identical conditions will give a density of 1.5. Although slightly less convenient, this may also be done from an H and D curve.

Density versus Thickness

(See Figure 41.)

When many curves similar to these are made varying only time and thickness, a standard technique chart may be drawn up by choosing some fixed density and plotting exposure versus thickness at that density.

This curve may also be useful in measuring object thicknesses by densities. However, for *each* film made for measurement an accompanying wedge or reference film must be simultaneously exposed and developed. Otherwise uncontrollable variation prohibits accuracy.

Chapter 5

FILM PROCESSING

Interaction of Film and Processing Chemicals

The photographic process depends upon the fact that the reduction of the silver ion to metallic silver by a developing solution proceeds much more easily for an exposed silver halide grain than for an unexposed grain. There are two kinds of development which occur simultaneously in ordinary developers, physical development and chemical development.

A physical developer contains a reducing agent, free silver ions, and a weak acid. These solutions deposit silver upon suitable nuclei, such as those formed in the silver halide grains by exposure to radiation. In a true physical developer, therefore, the silver which forms the image is not derived from the silver halide of the emulsion.

In chemical development the silver bromide grain itself is reduced starting from specific points of the surface. The developer does not contain any free silver ions and is a stronger reducer.

In ordinary developers both types of development occur since they contain substances which dissolve silver bromide, the commonest of which is sodium sulfite. The reduction of the silver is initiated by chemical development, but physical development occurs in the later stages. All x-ray developers are alkaline solutions.

Chemically the speed of development changes with the alkalinity of the solution. Fast developers like Kodalk and Supermix are highly alkaline. Appreciable amounts of oxidation products impede development, but secondary chemical reactions which eliminate these oxidation products proceed at a rate proportional to the alkalinity of the solution.

Also, gelatins soften, expand, and absorb solutions more easily in the presence of an alkali. Thus the alkali serves a mechanical as well as a chemical purpose.

Ingredients of Developers

A developer generally consists of a reducing agent, a preservative, a restrainer, and an alkali.

Reducing Agents—There are literally hundreds of reducing agents but the commonest are metol or elon (methyl-P-aminolphenol) and hydroquinone. Metol is quick acting and brings out the latent image almost immediately. It does not develop deep blacks but is responsible for the intermediate tones and detail. A developer containing only metol as a reducing agent is soft and fuzzy. Hydroquinone is slow acting; the latent image appears near the end of the development. It produces deep black deposits with sharply defined edges. It is a hard developer. Ordinary x-ray developers contain both these chemicals.

Preservative—Excessive oxidation and consequent fast deterioration of the developer is prevented by a preservative such as sodium sulfite. The oxidation of both metol and hydroquinone is reduced to a minimum in the pressure of sodium sulfite. Development of unexposed silver halide grains is also prevented by a sufficient concentration of sulfite particularly in the presence of hydroquinone.

Sulfite is also a halide solvent and tends to retard normal chemical development and accelerate physical development.

Restrainer—Some chemical agent is usually employed to restrain the production of fog. Potassium bromide is one of the most common. The reaction of antifoggants is not clear. However, they postpone the appearance of fog until after the latent image is developed. In development the bromide causes an initial retardation, the length of which depends on exposure and bromide concentration. The shape of the H/D curve is altered by bromide, especially the inertia point.

Alkali—A constant level of alkalinity is of

the utmost importance in a developer. Most of the developing agents do not develop without alkali. The rate of development increases with alkalinity, but this reaches a limit after which no increase in alkali will increase the rate of development. The common alkalis are carbonates and for fast, contrasty developers, hydroxides.

Fixation

In addition to the reduced metal which forms the image, the developed film contains the residual silver halide unaffected by the developer. It is held in a gelatin layer which is swollen with a solution of sodium carbonate or other alkali and contains also partially oxidized products from the developer. Fixing should dissolve the excess halide; secondarily it should stop development, prevent organic stain and harden or check the swelling of the gelatin.

Sodium thiosulfate or hypo is an excellent halide solvent and most commonly used. Many complex products are formed in the action of hypo on the silver halides.

Long before the hypo of a fixing bath is exhausted the solution must be discarded because the complex products of the silver halide and hypo reaction tend to become adsorbed to the gelatin or silver grains of the image. They are not readily washed out and so remain in the film where they later decompose and cause stain.

The addition of 2-4% ammonium chloride to fixers accelerates the rate of fixation considerably.

At the end of the clearing time 5% of the original silver halide remains in the film, but at the end of two times the clearing time 0.25% remains. For old fixer this is insufficient time because of adsorption. It is best to clear in one bath and transfer to a second for an equal length of time. Washing will then complete the halide removal.

To prevent oxidation of developer and staining in the fixing tank and to arrest development rapidly, it is desirable to use an acid solution of thiosulfate. But hypo is unstable in the presence of an acid and deposits sulphur. This reaction can be prevented by the addition of sulfite to the solution.

The hydrogen ion concentration or acidity of the fixer must be high enough to neutralize the carried over developer and not so high as to deposit sulphur (*p*H 4.0-6.5) and must carry large reserve acidity. Acetic acid satisfies these requirements.

Therefore, an ordinary fixer contains hypo, sodium sulfite, and acetic acid. Sometimes other acids than acetic are used, like boric acid. Potassium alum is sometimes employed as a hardener, and ammonium chloride added as an accelerator.

Practical Considerations

Because of the simplicity of processing films, the technician is apt to forget that developing, fixing, and washing the film is still a sensitive and delicate chemical-physical reaction. Extreme care is essential.

Because so many factors in the radiographic process are variable it is important to standardize darkroom procedure. Ideally, every film exposed to the same amount of radiation should become a radiograph of identical densities and range. This is not easy. Therefore, all darkroom operations must be rigidly standardized.

Mixing—In general, solutions used in the laboratory, whether in powder or liquid form are already made up by the manufacturer whose directions must be followed implicitly. Deviation here will cause chemical deterioration. The preservative must be added before the reducing agent or halide solvent. Mixing temperature must not be over 125°F. Mixing vessels or pails should be made of enamelware, stainless steel, glass, hard rubber, or glazed earthenware. Metals, such as aluminum, galvanized iron, tin, copper, and zinc, will cause contamination and result in fog on the radiograph. Solutions should be stirred each day before use. Wooden paddles about 36 inches long, one for developer and one for fixer, are most practical for stirring. If they are washed thoroughly and hung up immediately after use, drying will take place rapidly, and there will be no danger of contamination.

The developing tank or insert should be covered when not in use to prevent excessive surface oxidation. Each day before developing and stirring, the surface scum should be re-

Chapter 5

FILM PROCESSING

Interaction of Film and Processing Chemicals

The photographic process depends upon the fact that the reduction of the silver ion to metallic silver by a developing solution proceeds much more easily for an exposed silver halide grain than for an unexposed grain. There are two kinds of development which occur simultaneously in ordinary developers, physical development and chemical development.

A physical developer contains a reducing agent, free silver ions, and a weak acid. These solutions deposit silver upon suitable nuclei, such as those formed in the silver halide grains by exposure to radiation. In a true physical developer, therefore, the silver which forms the image is not derived from the silver halide of the emulsion.

In chemical development the silver bromide grain itself is reduced starting from specific points of the surface. The developer does not contain any free silver ions and is a stronger reducer.

In ordinary developers both types of development occur since they contain substances which dissolve silver bromide, the commonest of which is sodium sulfite. The reduction of the silver is initiated by chemical development, but physical development occurs in the later stages. All x-ray developers are alkaline solutions.

Chemically the speed of development changes with the alkalinity of the solution. Fast developers like Kodalk and Supermix are highly alkaline. Appreciable amounts of oxidation products impede development, but secondary chemical reactions which eliminate these oxidation products proceed at a rate proportional to the alkalinity of the solution.

Also, gelatins soften, expand, and absorb solutions more easily in the presence of an alkali. Thus the alkali serves a mechanical as well as a chemical purpose.

Ingredients of Developers

A developer generally consists of a reducing agent, a preservative, a restrainer, and an alkali.

Reducing Agents—There are literally hundreds of reducing agents but the commonest are metol or elon (methyl-P-aminolphenol) and hydroquinone. Metol is quick acting and brings out the latent image almost immediately. It does not develop deep blacks but is responsible for the intermediate tones and detail. A developer containing only metol as a reducing agent is soft and fuzzy. Hydroquinone is slow acting; the latent image appears near the end of the development. It produces deep black deposits with sharply defined edges. It is a hard developer. Ordinary x-ray developers contain both these chemicals.

Preservative—Excessive oxidation and consequent fast deterioration of the developer is prevented by a preservative such as sodium sulfite. The oxidation of both metol and hydroquinone is reduced to a minimum in the pressure of sodium sulfite. Development of unexposed silver halide grains is also prevented by a sufficient concentration of sulfite particularly in the presence of hydroquinone.

Sulfite is also a halide solvent and tends to retard normal chemical development and accelerate physical development.

Restrainer—Some chemical agent is usually employed to restrain the production of fog. Potassium bromide is one of the most common. The reaction of antifoggants is not clear. However, they postpone the appearance of fog until after the latent image is developed. In development the bromide causes an initial retardation, the length of which depends on exposure and bromide concentration. The shape of the H/D curve is altered by bromide, especially the inertia point.

Alkali—A constant level of alkalinity is of

apparently the solution is yet not in equilibrium with the oxidation products which temper it. Therefore, it is sometimes recommended that a small quantity of the discarded developer be saved and mixed with the new.

Replenisher Method

By using replenisher, the developing time can be kept constant throughout the life of the solution. In this method films should be removed from the developer quickly and the excess developer not allowed to drain back into the tank. Normally, this should carry out the proper amount of solution. Approximately one gallon of replenisher should be added for every 40 14x17 films or their equivalent area. If sufficient solution has not been removed by the carry over, the films have been allowed to drain too much and enough solution must be removed from the tank to allow the addition of the proper amount of replenisher. The solution should be discarded when the replenisher used equals four times the original quantity of developer.

Agitation

In order to prevent films' sticking together, eliminate air bubbles on the surface of the film, and principally to insure uniform development, agitate the film during developing. The developer in intimate contact with the film quickly becomes exhausted; if it is not renewed, the development slows down and become uneven. Therefore, the film should be agitated thoroughly (but not lifted out of the solution) for five seconds at least once every minute.

Rinsing

After development films should be rinsed in clean water for about 30 seconds because the gelatin of the emulsion, even when well drained, retains a considerable amount of developer. If films are transferred to the fixer directly, the alkali from the developer will neutralize some of the acid in the fixer. In a short time, the chemical balance of the fixer will be impaired, the hardening action lost, and stains will be produced. Rinsing time may be extended to 1½ minutes, if necessary, to prevent mottling.

Stop Bath

To prevent more completely the introduction of developer into the fixing bath, a stop bath consisting of 6 ounces of 28% acetic acid per gallon of water may be used. Films placed in this bath for about 30 seconds before going into the fixing bath will be fairly free from alkali, and the life of the fixing bath will be prolonged. The stop bath should be replaced as soon as it fails to show an acid reaction to litmus paper. If a carbonate is an ingredient of the developer, tiny bubbles may form in the emulsion. Keeping all solution temperatures uniform will help avoid this. If not, omit the stop bath.

Fixing Bath

When the films are first placed in the fixing bath, and once or twice during fixation, the hangers should be agitated to insure uniform action of the chemicals. If one fixing tank is used, Types M, A, F, Super Ray A, B, and High Speed should be left in the solution at least 15 minutes and Type K, 25 minutes. Two tanks of fixer are preferred, however. In this case films should remain 5 minutes in the first insert and 5 to 10 minutes in the second. If the clearing time in the first insert exceeds 5 minutes, the solution should be discarded. Number 2 insert is then moved up to Number 1 and the fresh solution replaces Number 2. An exhausted fixing solution is not renewable by the addition of chemicals and must be discarded when clearing time becomes excessive.

Washing

X-ray films should be washed in running water that is so circulated that the entire emulsion area will be washed. The bar of the hanger and the top clips should always be covered completely by water.

Efficient washing of the film depends both on sufficient flow of water to carry hypo away rapidly and on adequate time to allow the hypo to diffuse from the film. To wash x-ray film the hourly flow of water should not be less than 12 times the volume of the tank, and time of washing should not be less than 20 minutes. Insufficient washing leads to later discoloration, fading of the image, and corrosion of the image by the residual hypo.

Wetting Agent

In order to prevent water spots and speed drying, the film is given a final rinse for 2 or 3 minutes in a solution of wetting agent. G. E. supplies a wetting agent; Eastman markets one called "Spot Preventive", and it is sold also under the name "Aerosol." One part in 10,000 of a 10% solution is said to be sufficient. It is best to test the solution with a dry film spotted with talcum powder. If it wets, the solution is strong enough.

It is also recommended for use in developer to eliminate non-development where films touch, and pin holes due to air bubbles. Its action is to reduce the surface tension of the solution and wet all points equally.

FIGURE 46. Removing film from box

Draining

In the interest of cleanliness and convenience, films should be drained of all excess water before being placed in a drier. If the lower edge of the film is placed at a slight angle the water will drain more efficiently. However, water from the hanger should not be allowed to drip upon the film or stains will result. Draining prevents crowding the drier and makes the drying process most efficient.

Drying

Most driers are simply boxes through which is forced a stream of warm dry air. More recently infra-red lamps are being used. Great care must be exercised in placing films in the drier. If the film is at all slack in the hanger, it is possible for films to touch. Films dried touching each other are ruined beyond redemption.

Control of Quality

To obtain some information as to the accuracy of mixing and deterioration of processing solutions it is useful to keep a record of the specific gravity of the solutions. This information is comparative at best and is most useful as a gross check on the inclusion of all ingredients of a solution.

A more accurate indication of the condition of a solution is obtained by *p*H or hydrogen ion concentration measurement. Both developer and fixer operate efficiently in a narrow range of *p*H. Daily *p*H measurement should be made if possible.

The most accurate indications of solution condition are the processing, density measurement, and the plotting of the sensitometric curves of standard film wedges. These exposed standard film strips may be obtained from the Photo Science Laboratory, Naval Air Station, Anacostia, D. C.

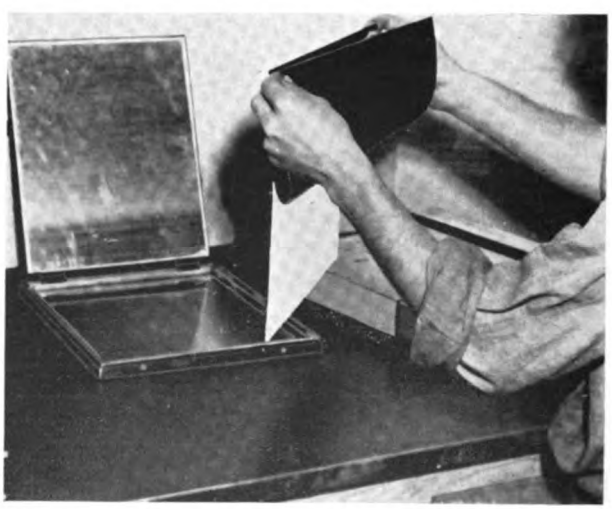


FIGURE 47. Removing paper from film

However, the most satisfactory method of obtaining consistently high quality films is to exercise scrupulous care and attention to detail in the darkroom.

Cleanliness

More films are spoiled in the darkroom than in the exposure room. Aside from carelessness, the major fault is lack of cleanliness.

Screens must be examined each time before a film is placed in a cassette or holder. Most dirt is removable by brushing with a soft cloth or camel's hair brush. Explicit directions for cleaning screens are contained in Chapter 7.

Hypo spilled over the side of the tank and on the deck can cause endless trouble. When it dries, the dust is stirred about and settles on the film. Wherever it settles, it corrodes. It can spoil chemicals, film, equipment, paint—almost anything.

Toweling must be supplied. Hands must be always dry and clean when handling any darkroom equipment. The danger of contamination is always present.

FIGURE 48. Placing film in cassette without fingering the film

FIGURE 49. Removing film from cassette

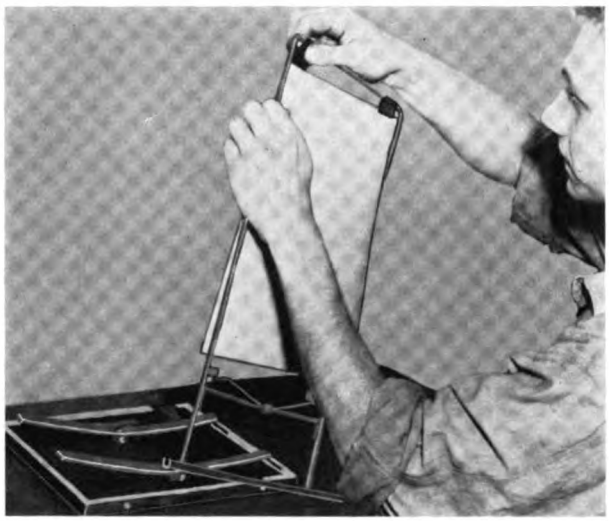


FIGURE 50. Cassette closed; Fastening first corner

If the water level in the washing tanks is too low, the hangers will become sources of stain. The water must cover the tops of the hangers at all times. They should never be reused unless thoroughly dry.

Film Handling

Extreme care must be used in the film loading room to prevent inadvertent light fogging. After using, covers should be immediately replaced on film containers. Holders developing light leaks should be discarded; do not attempt repair.

When loading holders or cassettes, they should be opened and examined for cleanliness. The film should be removed from the box still sheathed in the black paper. Remove the paper; do not slide the film out of it. Place in the holder between screens with due regard for paper flaps; close and lock.

In removing film from the holder, open the holder completely; do not slide the film out. Flip the film (reverse, bottom side up) and punch the serial number in the upper right hand corner.

To place in the hanger, hold the upper right hand corner between the right thumb and forefinger and fasten bottom hanger clip (held in left hand) to film. Fasten the second bottom clip and finally the top clips. The film should now be perfectly flat and taut with the punched number at the bottom of the hanger. If it is not, remove and repeat. If the number is placed at the top of the hanger, the holes will cause dark streaks as the fresh developer drains down.

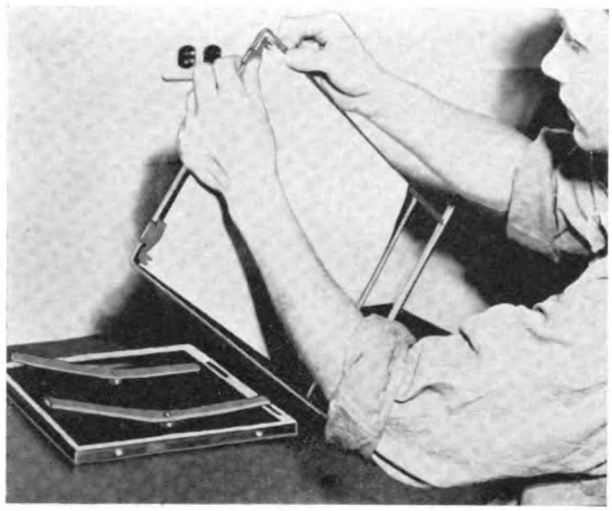


FIGURE 51. Second corner

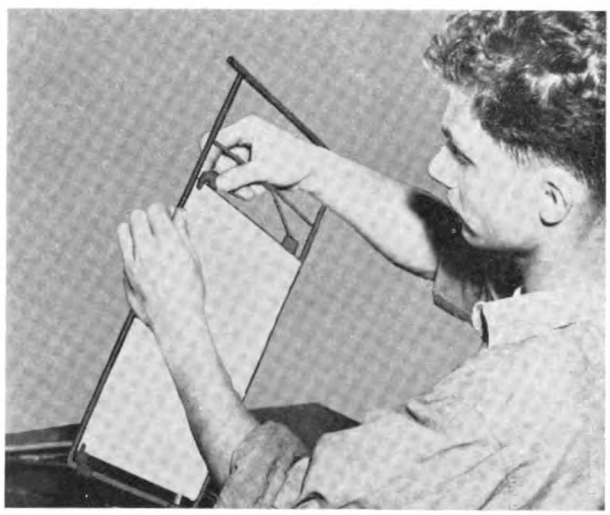


FIGURE 52. Third corner

FIGURE 53. Last corner

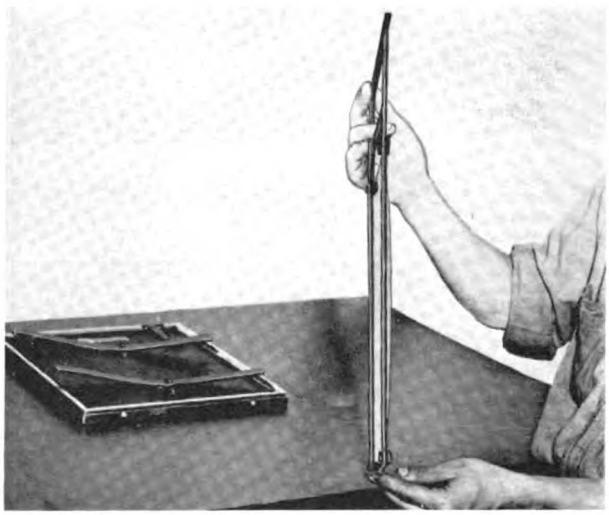


FIGURE 54. Film should be flat and taut

Chapter 6

SCATTERING AND FILTRATION

Scattering

Scattering is the process of producing x-rays by irradiating matter with x-rays. The intensity of scatter produced by the primary radiation is a function of the kilovoltage of the primary beam and the material radiated. This scatter comes from four distinct processes; formation of characteristic x-rays, unmodified scatter, Compton scatter, and pair production. Regardless of how the scatter is produced, the effect on the film is the same, causing high over-all density, but contributing nothing to the radiograph. See Figure 55.

The ratio of Compton scatter, the principal type, to direct radiation is inversely proportional to the voltage and directly proportional to the density and thickness of the scattering material. There are generally two types of scatter reaching the film, forward scatter which tends to increase the area of the beam and back scatter. The shape of the object is also a large factor in the scattering process.

The effects of scattered radiation can be seen by an analogy to light. Figure 55 shows the effect on sensitivity of scattered light. As the ratio of scattered to direct light increases, the sensitivity becomes poorer.

The same effect is obtained in radiography. The ratio of scattered to direct radiation for the range of voltage used, is shown in Figure 58. This scattering factor, as it is called, affects the sensitivity of the radiograph proportionally.

Objects having the greater thickness in the center than on the edge have a higher scattering factor. The reason for this can be seen, since the thicker section reduces the intensity of the beam more than the thinner section. Therefore, the radiation from the thinner section scatters into the area of the thicker section on the film. This is called *"undercutting."* Due to the scattering, the separation between the two sections is not distinct.

There are several methods of eliminating scatter or secondary radiation.

Filtration

Filtration is the process of placing some absorber, usually copper or lead, in the beam either at the tube or between the object and the film. The filter absorbs the longer wave length x-rays, thus giving essentially a harder beam. That this is advantageous may be seen from Figure 58, since scattering factor is a function of the effective wave length. This method reduces the scatter satisfactorily in nearly every case.

In practical radiography the presence on the film of evidence of excessive scattering indicates that a higher voltage is necessary. If a higher voltage is not available, the position of the filter to be used is of some importance. The interposition of a filter in the beam between target and film will reduce the sensitivity of the radiograph because of the additional thickness the radiation must penetrate. This may be undersirable.

In examining cylindrical objects if high sensitivity must be had in the center of the cylinder, a filter should be omitted in spite of the undercutting along the parallel sides. If an average over-all sensitivity is desired (elimination of undercutting and lessened sensitivity in the interior), the filter at the tube will give slightly better results than a filter at the film. However for differential masking or filtering, i.e., a 40-mm. steel projectile with an aluminum fuze, lead between the object and film will give good results.

Coning

Coning is the process of limiting the field of radiation to the area of the film. This reduces the scattering by reducing the amount of radiation that passes through the object. In this case the radiation will not scatter on to the

699810—46—4

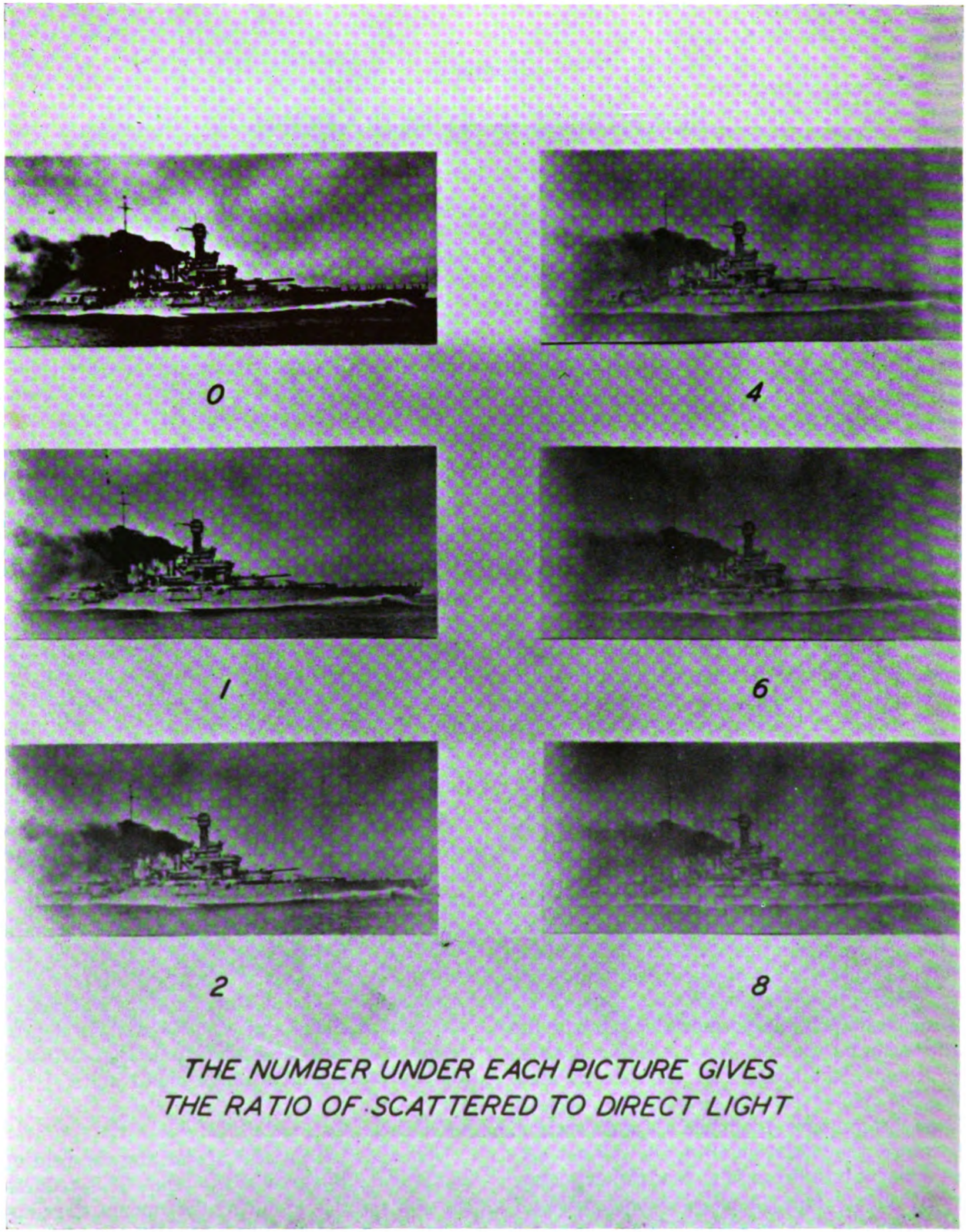


FIGURE 55. Effect of scattered radiation on an image

film from a section of the object that is not being examined.

These cones are made of lead so that the scattering from the cone itself is a minimum.

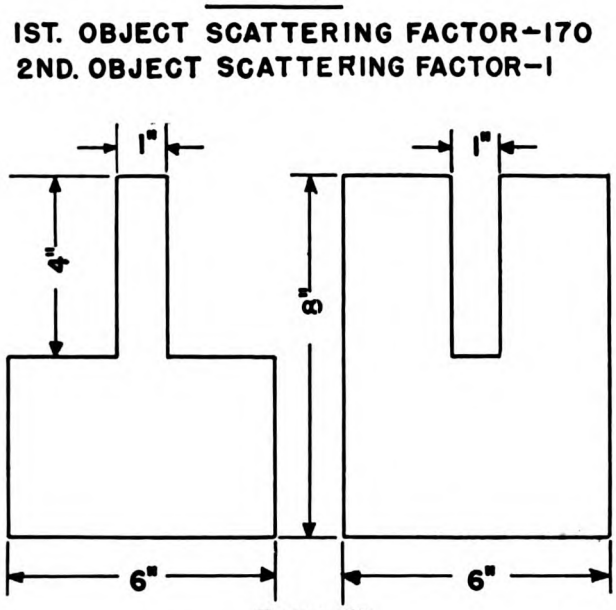


FIGURE 56

Bucky Grid

The Bucky grid is a device for eliminating the scatter between the object and film by a moving system of lead strips perpendicular to the beam. These lead strips have the function of absorbing the divergent scattered rays from the object itself so that most of the exposure is made by the primary rays emanating from the focal spot of the tube. Only the x-rays passing through the object parallel to the strips strike the film. Figure 61 is a photograph of an experimental Bucky grid designed for two million volt radiography.

Use of the Bucky grid increases the exposure time by a factor of 2 to 4 depending on its effectiveness. The more scatter elminated, the longer is the exposure required to get a density on the film.

Object to Film Distance

By increasing the distance between the object and the film, the scatter reaching the film may be reduced to some extent.

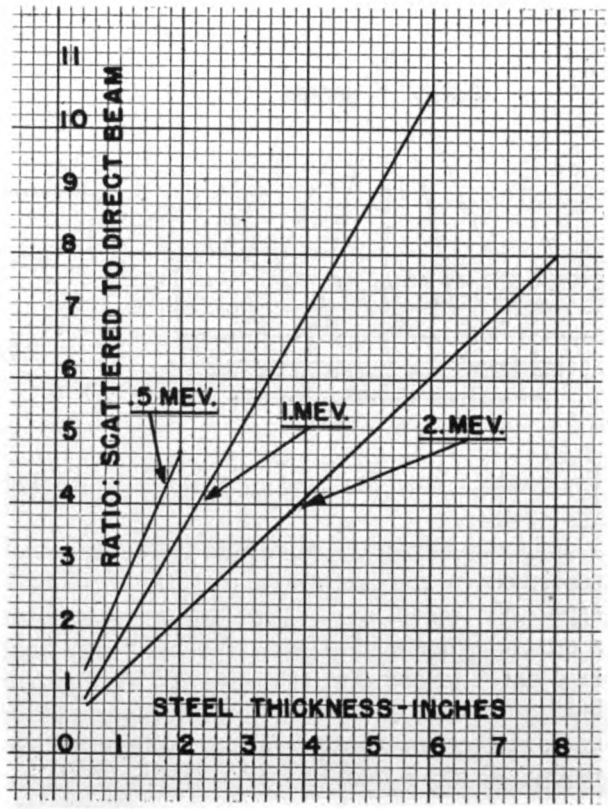


FIGURE 57

The objection to using this method is the requirement of an infinitely small focal spot. The fuzziness due to the spot size reduces the gain made by eliminating the scattered radiation. This method is not recommended because of the finite spot size. Projections made at 2 M.E.V. on the Van de Graaff prove this reduction in scatter, but for information on the film,

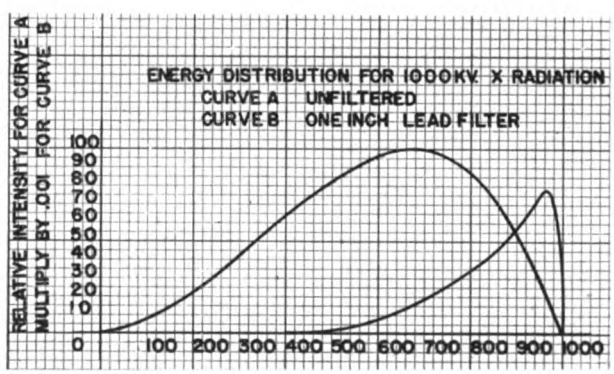


FIGURE 58. Comparsion of filtered and unfiltered beam. Curve B has sharper peak

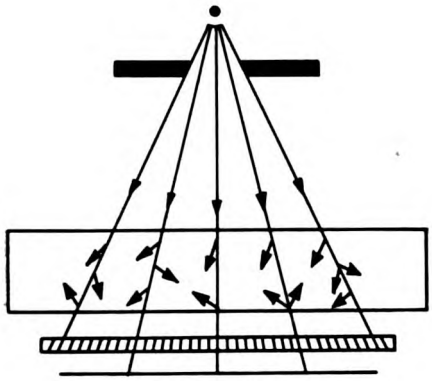


FIGURE 59

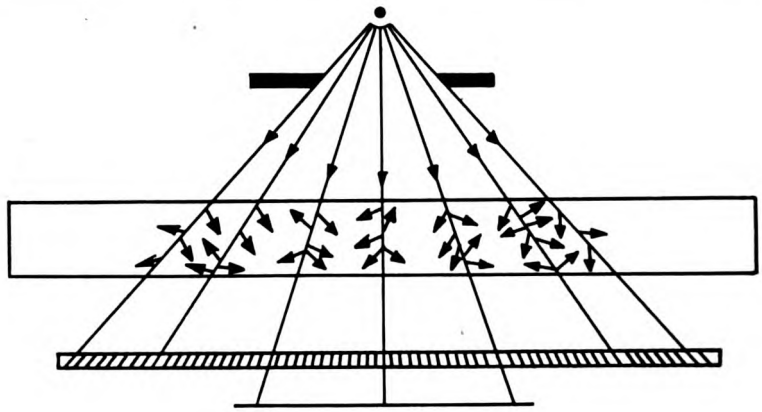


FIGURE 60

the contact shot is superior despite a .01-inch spot size.

It is also necessary to eliminate the radiation scattered in the backward direction. This is especially essential if the film is placed on a concrete or steel surface. Normally the back lead sheet in the film cassette will absorb this back scatter at the very lowest voltages. When back scatter is expected in low voltage radiography, 1/8 of an inch of lead will absorb it; for 2 million volt radiation 1/2 inch of lead is used beneath the film. It is said that for very high voltages back lead is not used because most of the radiation is in the forward direction; however, even at 20 M.E.V. back paper patterns have been obtained in standard holders.

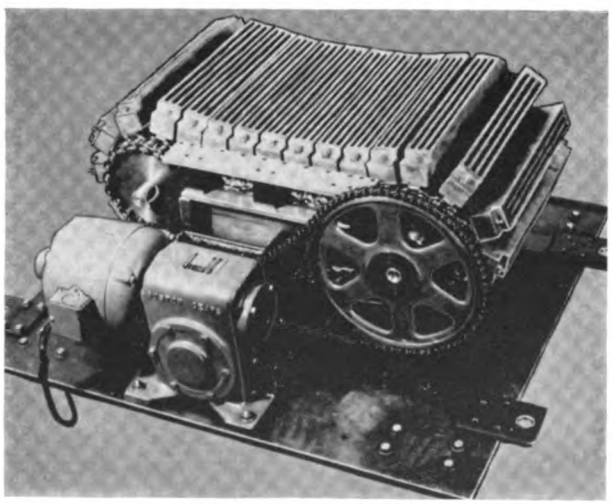


FIGURE 61. Bucky grid for 2 M.E.V. radiography

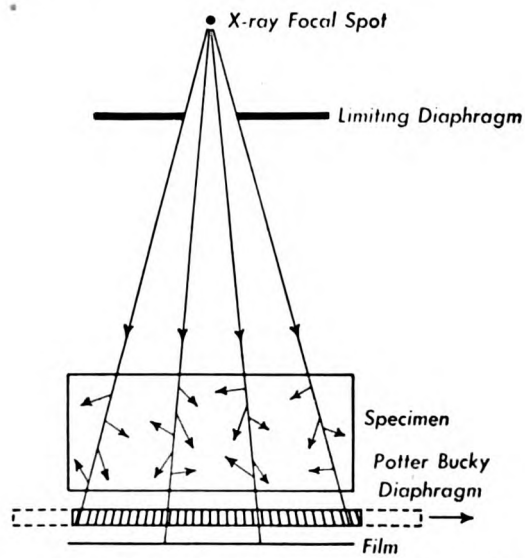


FIGURE 62. Schematic diagram showing how the primary x-rays pass between the lead strips of the Potter-Bucky diaphragm while the secondary x-rays are absorbed because they strike the sides of the strips

Chapter 7

SCREENS

Lead

Theory of Lead Intensifying Screens

The intensification of lead screens is a result of the ejection of photoelectrons from the surface of the irradiated lead screens with the consequent emission of characteristic radiation.

When a photoelectron is ejected from an atom of lead in the screen an electron from another energy level falls in its place and in so doing emits characteristic radiation which reacts with the film emulsion. The high energy photoelectron in leaving the screen strikes the film and ionizes the atoms of the emulsion of the film. Probably the greatest reaction is caused by each photoelectron striking and ionizing a large number of the atoms of the sensitive emulsion. The total of these effects is known as the intensification.

Then, if the primary radiation is of high enough energy to eject the photoelectrons from the lead screens, the object thickness and density great enough to filter out those wave lengths incapable of producing the photoelectrons and the absorption of the lead screen small enough, there will be an intensifying action of the film from the use of lead screens. In addition the lead screen filters out a large proportion of the soft scatter striking the screen at large angles.

Intensification Factor

This factor is the ratio of the exposure time with screens to the exposure time without screens with reference to a definite density.

The intensification factor increases with hardness of the radiation and object thickness and density up to approximately 400 KV; then it is practically constant at least up to 20 M.E.V. In radiography of aluminum at 150 KV the thickness must be about 6 inches in order to obtain any intensification by the use of lead screens.

In radiography of ½" steel, the intensification factor is 16% at 150 KV and in the neighborhood of 300% at 400 KV.

The following is a chart of relative exposure times using plain holders and lead screens at different kilovoltages, the focal-film distance and a film density of 1.0 being the same in all cases with no object or filtration:

TABLE III

EXPOSURE FACTORS WITH AND WITHOUT SCREENS FOR ZERO THICKNESS

	Lead Screens	*Exposure Factors*	*Plain Holders*	*Exposure Factors*
Kelly-Koett	60 KV	120	60 KV	5
	100 KV	16	100 KV	2
	150 KV	5	150 KV	1
General Electric	200 KV	10	200 KV	4½
	300 KV	2½	300 KV	1¾
	400 KV	1	400 KV	1

(Compare ratios of exposure factors horizontally.)

Filtering Action

In addition to their intensifying action, lead screens act as filters of scattered radiation. The front screen absorbs a large percentage of the longer wave length scattered radiation (due to its longer path through the lead because of its angle of projection and because it is more easily absorbed than the more penetrating primary radiation). The back screen, in addition to its intensifying action, absorbs the back scatter or radiation scattered back from exposure table walls, floors, etc.

Quality of Result—Graininess

In radiography of dense and irregularly shaped objects, the improvement in definition and decrease of undercut by using lead screens is very noticeable largely due to the filtering action of the lead. At lower kilovoltages the use of lead screens may require longer exposure time, but if the quality of the radiograph is better than a direct exposure, lead screens should be used.

The effect on graininess in the radiograph by the use of lead screens is practically negligible.

Efficient Thickness of Screens

The ejected photoelectrons come from an extremely small layer of the lead closest to the film. Usually though, the front screen is about .005 inch thick which is a compromise between absorption of secondary radiation and intensification of the primary radiation. The back screen is usually .010 inch thick in order to absorb all of the back scatter. At 2 M.E.V. the optimum lead screen thickness is .007 inch. However, the gain between 5 and 7 thousandths inch is very small.

Effective Voltage

The intensification will begin when the wave length of the primary radiation is 0.141 Å or less (the K alpha 1 line of lead). This is the shortest wave length emitted when the tube voltage is at about 88 KV and in order for the effective wave length to be of this value the tube voltage would have to be 1.3 times 88 KV or approximately 114 KV.

However, with no filtration and no object, the intensification just overcomes the absorption of a .005″ Pb screen at about 400 KV. In other words a film would have the same background density whether exposed in a plain holder or .005″ Pb screen holder at this KV.

Cleaning and Care

Proper care of the lead screens is very important if the best radiographic results are to be obtained. If the screens are not smooth and free of streaks, indentations and corrosion or if there are foreign substances between the screen and film, the result will be light areas or spots on the developed film. Any foreign substance, corrosion, etc., will absorb the photoelectrons and so decrease film density. In the chapter on film defects will be found a description of some which are due to screen defects. Anything which will eliminate the particular screen defect should be done. It is advisable to wipe off the screens each time before loading with a soft lintless cotton cloth to eliminate scraps of black paper and other dirt; at least turn the holder on edge or upside down so the larger particles will fall off. If the screens are damaged the holder should be set aside for later repair or replacement of screens.

If the screens become corroded from handling with wet hands they may be cleaned by gently rubbing with a cotton cloth soaked in "bright work" polish. When the polish dries it may be wiped off with a dry cloth. There will still be some deposit on the screens which can be wiped off with a cloth dampened in gasoline or carbon tetrachloride. This must be followed by wiping with a clean dry cotton cloth. The holder should be left open for awhile afterwards to dry completely.

Scratched, dented, or streaked screens are not easily repaired and so should be discarded. Bent or wrinkled screens can sometimes be rolled out smooth so that they will again make good contact with the film.

Making Screens

Very suitable screens may be made using old film and smooth sheet lead of the proper thickness. The old film is sprayed with a thin rubber cement; when this has dried, the lead and film are lightly rolled together. It may be necessary in some cases to roughen the surface of the film with fine sandpaper for the cement to adhere properly. The finished screen is very flexible and will not crimp or wrinkle easily. The front and back screens can be hinged with adhesive or masking tape for easy handling when placed in a cardboard holder. Light cardboard backing is easier to cement and is almost as serviceable.

It has been found that soft lead sheets are more easily rolled out smooth than the harder ones with a high tin or antimony content. When even minute wrinkles are left in the screen, the results will be poor, especially at low voltages. For best results the lead should be rolled on a

clean glass surface with a smooth hard roller which covers the entire width of the lead.

Lead Screen Cassettes

Cassettes are film and screen holders which, when closed, hold the screens in good contact with the film by means of a felt lined back plate and spring clamps. Good screen-film contact is necessary to obtain good detail on the film.

Because the screens are held against the film by spring pressure, good screen-film contact is maintained regardless of the cassette position. When the film has to be in any position other than horizontal, better results will be obtained by using cassettes.

Use of Plain Holders

Plain holders are used in the radiography of thin sections at low kilovoltage, 150 KV and lower. Their only function is to prevent the film from becoming fogged by light. This type of holder does not absorb scatter, in fact may even contribute to it.

Due to scatter, sensitivity is poorer in thicker sections when using plain holders. Following are some examples of sensitivities obtained at the Navy laboratory: ½" steel, 150 KV, 3 ft. F-F distance, "A" Film, Pb screens, 0.6% sensitivity; ½" steel, 150 KV, 3 ft. F-F distance, "A" Film, plain holder, 0.8% sensitivity; 1" steel, 400 KV, 12 ft. F-F distance, "A" Film, Pb screens, 0.6% sensitivity; and 1" steel, 400 KV, 12 ft. F-F distance, "A" Film, plain holder, 1.0% sensitivity. "Sensitivity" is the smallest thickness of flaw which can be seen on the radiograph, expressed as a percentage of the total thickness of material.

Because of intensification and absorption of scatter, film contrast will be increased in lead screens over that in plain holders.

The usual plain holder is made up of two hinged cardboards between which is placed a light-tight paper envelope to hold the film. This type of holder should not be used when the kilovoltage is lower than about 30 KV because the inhomogeneities in the cardboard show quite plainly on the radiograph. For lower kilovoltages, satisfactory holders can be made by taping two completely black films together with black masking tape, leaving a flap on one end. This type of holder is quite satisfactory as long as reasonable precaution is taken not to scratch some of the emulsion from the film of the holder.

In some cases it may be necessary to tape a sheet of lead to the back side of the holder to absorb the back scatter. When radiographing heavier sections using standard plain holders it may be necessary to place a sheet of cardboard in front of the backing lead in the holder to absorb the back photoelectron scatter from the lead which would cause an imprint of the folded envelope on the film.

Calcium Tungstate Screen Cassettes

Theory

Calcium tungstate screens when impinged upon by x-rays or gamma rays transform the energy of the radiation into radiation of longer wave lengths in the ultra-violet and visible blue-violet range. The energy of the impinging radiation transformed by the calcium tungstate, produces ionization or excitation or both within the atoms of the screen. In returning to their normal states the atoms produce fluorescence.

Two screens are usually used, one on each side of the film. The front screen is usually thinner than the back screen to minimize x-ray absorption. The intensifying screens and film combination when exposed to x-ray or gamma ray produce the latent image on the film partly by the action of the x-ray but mostly through the action of the ultra-violet and visible light. The necessary exposure time to produce a given density is thereby reduced. The ratio of the exposure time with screens to the exposure time without screens is known as the intensification factor.

Intensification Factor

The intensification factor at 70 KV generally given for "high definition" screens is about 10; medium or "par speed" about 20; and fast or "high speed" about 30, at a density of 1. These factors would be obtained upon exposure of the same type if film in plain holders and calcium tungstate screens with no object or filtration.

At the Navy laboratory tests have been made with the following results:

At 150 KV, 6 ft. focal-film distance, no filtration, at a density of 1, .35 inch steel, the intensification factor of "F" film in #245 screens over "A" film in lead screens is about 300 to 1.

At 400 KV, 12 ft. focal-film distance, no filtration at a density of 1, 1 inch of steel, the intensification factor of "F" film in #245 screens over "A" film in lead screens is about 165 to 1.

With radium, at 3 ft. focal-film distance, no filtration at a density of 1, the intensification factor of "F" film in #245 screens over "A" film in lead screens is about 90 to 1.

The highest intensification factor for calcium tungstate screens on the point of maximum efficiency for production of fluorescence occurs at about 150 KV.

The intensification factor increases as the film density increases. Therefore, by use of intensifying screens, the contrast is increased.

Quality—Graininess

The chief disadvantage resulting from the use of intensifying screens is the unsharpness of lines caused by the finite size of the crystals of the fluorescent material. The reason for this is that when an x-ray photon traverses part of a crystal the whole crystal lights up. In the "high-speed" screens the unsharpness due to crystal size may be several tenths of a millimeter and is most visible when the film density is in the range of .5 to 1.0.

When using "high-speed" screens the sensitivity is usually very poor. It is quite difficult to obtain better than 2% sensitivity using them.

Use

When dirty, these screens may be washed with mild soap and water. Dented or cracked screens must be replaced.

Calcium tungstate screens are used when the amount of radiation getting to the film is small, and would require impractical exposure times with other film and either lead screens or plain holders. They are used in industrial radiography at low voltages on thick metal sections and occasionally at high voltages or with gamma ray, on extremely thick sections. In medical radiography they are used when radiographing sections of the body which cannot be immobilized. They are also used when radiographing the thicker portions of the body to cut down on the amount of radiation or dosage that the patient is required to take.

Screen and Holder Defects

A discussion of most of these defects appears in the next chapter. Some of the more common ones are:

1. Black "sunbursts" caused by light leaking around the edges of cassettes and worn paper envelope corners of cardboard holders.
2. Poor screen contact which causes diffusion of photoelectrons from lead screens or light from fluorescing screens, thereby producing unsharpness of line.
3. Dents in screens produce results somewhat similar to poor screen contact except that when using lead screens the surrounding area is light because of the increased lead thickness due to angular penetration. The area under a dent in a fluorescent screen will appear dark on the film.
4. Scratches appear as dark streaks when using lead screens and light streaks when using fluorescent screens.
5. Dirt and foreign material on screens cause light areas on the film because of their absorption of light or photoelectrons from the screen.

Chapter 8

FILM DEFECTS

Sometimes when the finished radiograph is examined blemishes or impressions appear which do not reflect the image of the object examined. Unless there is extreme urgency these films should be discarded and new radiographs made. The prime rule is if the radiograph is not perfect, make it over again.

However, it is not always easy to determine the cause of the inferior result. Therefore about fifty sample defective films have been collected. Not all of these lend themselves to reproduction, so only a few are pictured here. A complete set of the original films are on file in the Ordnance Investigation Laboratory. By becoming familiar with the appearance and cause of these defects it is usually easy to track down and eliminate the cause of error.

Clayden Effect

Some of these defects are related to an effect discovered by Clayden who observed the lightning flashes sometimes appeared reversed on a photographic plate.

X-ray film is sensitive to pressure marks, x-rays, light shock (millisecond exposure to high intensity light), and low intensity light. An impression by any one of them can be made to be reversed by subsequent exposure to any other in the list following it but, under no circumstances, by exposure to any one preceding it.

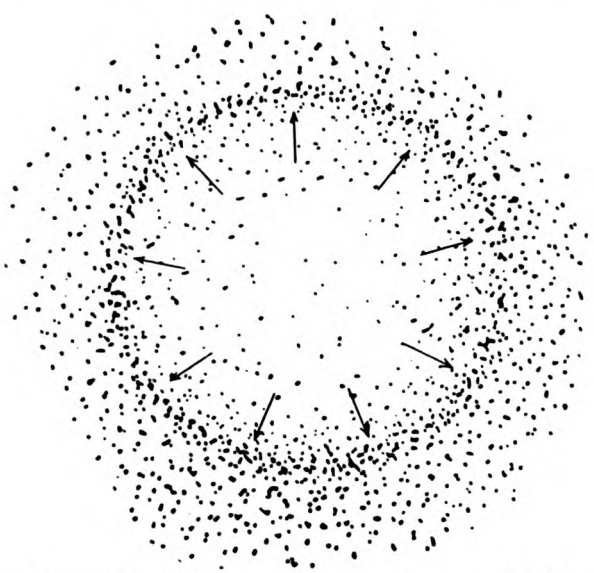


FIGURE 63. Diagram of the migration of silver particles in a water spot

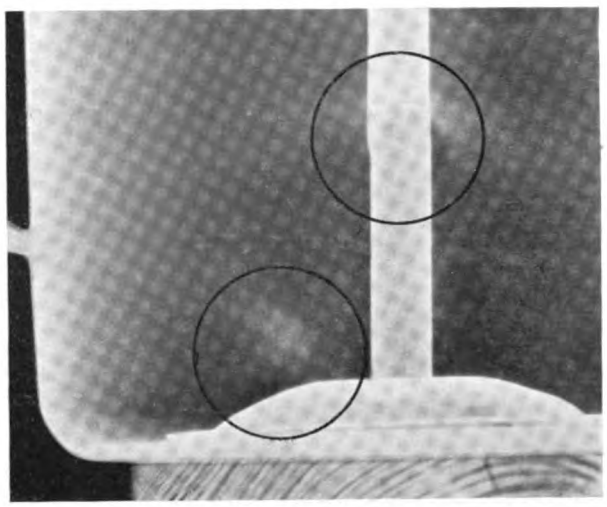


FIGURE 64. Crimp marks from careless handling. Before exposure; white finger prints

	Effects	
X-Ray Defects	*Before Exposure*	*After Exposure*
Pressure Marks	White	Black
Exposure to Light	Black	White
Static	Black	White

Characteristically the initial exposure desensitizes the emulsion so that subsequent exposure produces less effect than if the preexposure had not taken place.

Dichroic fog is a rare defect, though a few films spoiled in this way have been encountered. It causes the film to appear a different color by transmitted than by reflected light. It consists of metallic silver deposited in the gelatin by the action of the developer on silver halides which have been dissolved from the emulsion by solvents in the developing bath.

It is frequently confined to the surface and may be wiped off before the film is dried. After drying it can be removed by a brief rinse in a

permanganate bath followed by bisulfite treatment and thorough washing.

Water Spots

Offhand it would appear that water spots on a film might easily be removed by washing. However such is not the case. There is an actual migration of silver particles owing to tension: the silver particles collect in the drying edge as shown in Figure 63.

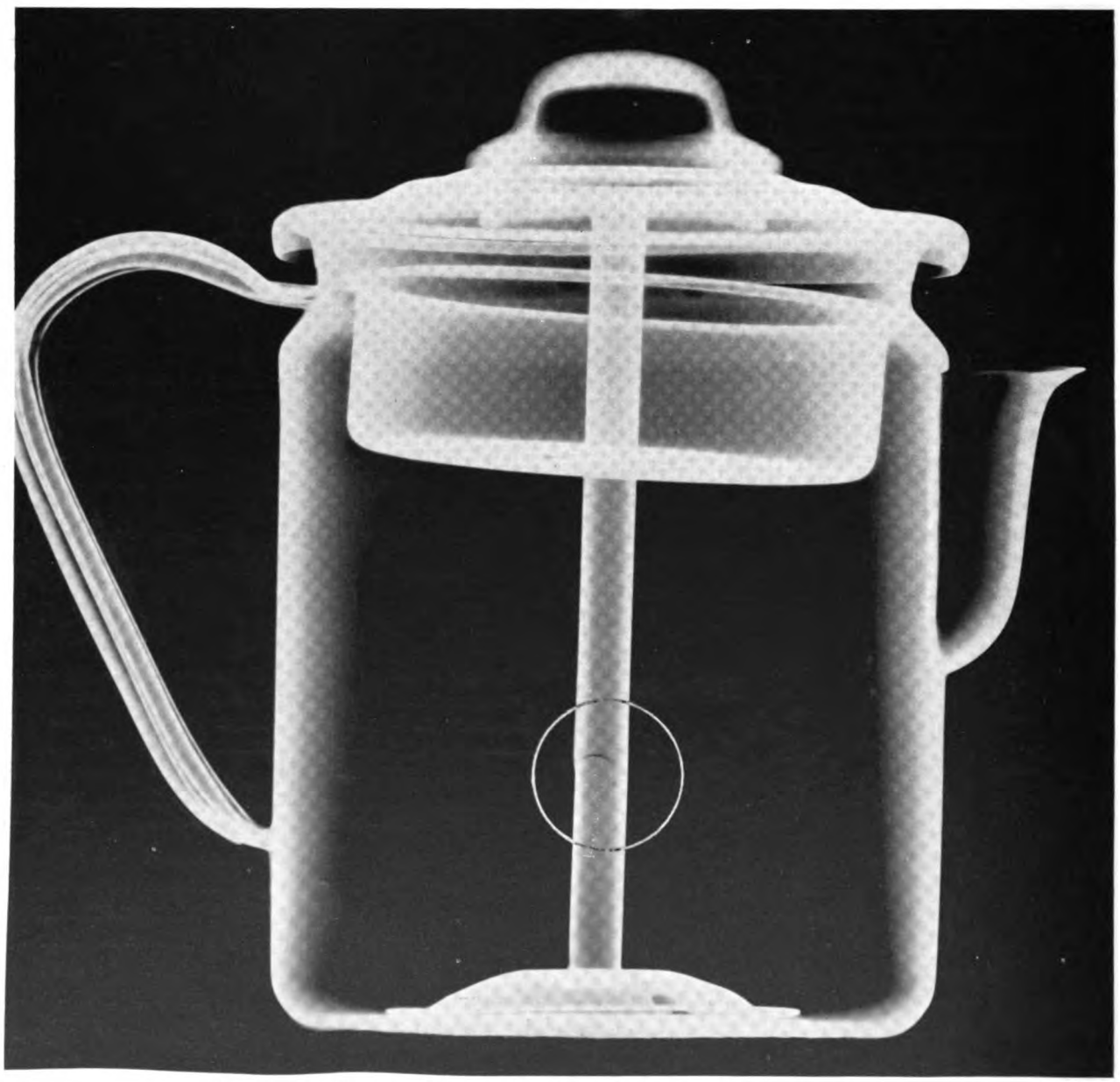


FIGURE 65. Crimp marks from careless handling. After exposure; black

FIGURE 66. Light fog. After exposure; reduced contrast and lightening of background density; developer stains (spots)

FIGURE 67. Light fog. Before exposure; increased contrast and darkening of background

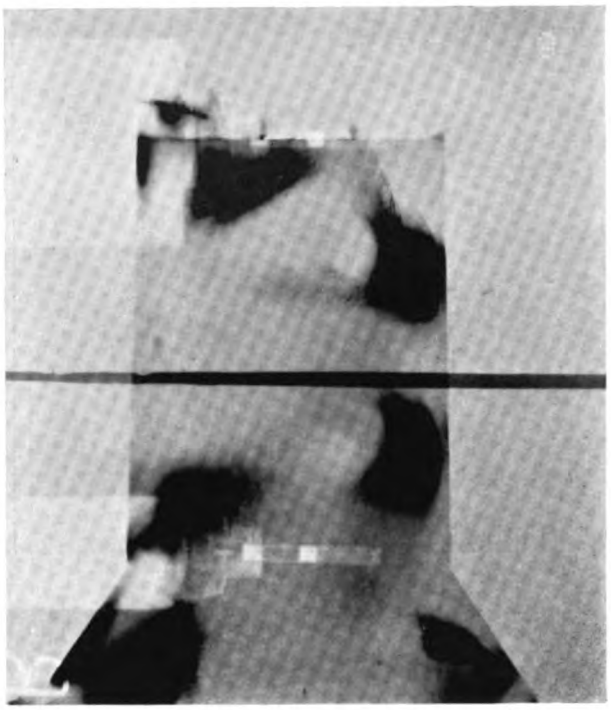


FIGURE 68. Paper pattern due to improper loading. Black areas are light-struck

FIGURE 69. Underdeveloped

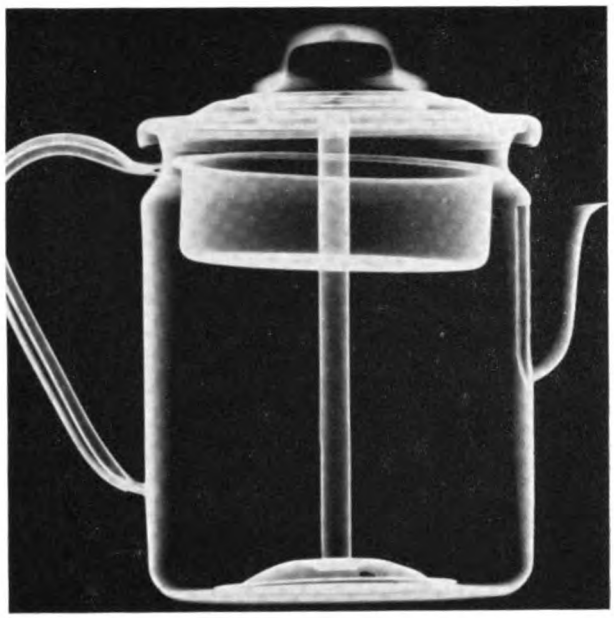


FIGURE 70. Overdeveloped

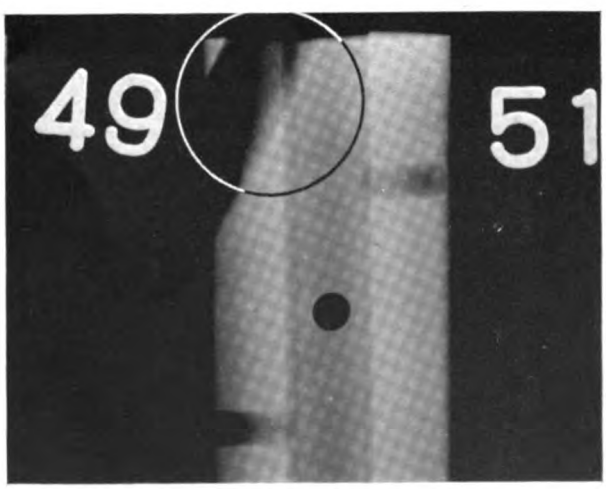


FIGURE 72. Films stuck together in hypo

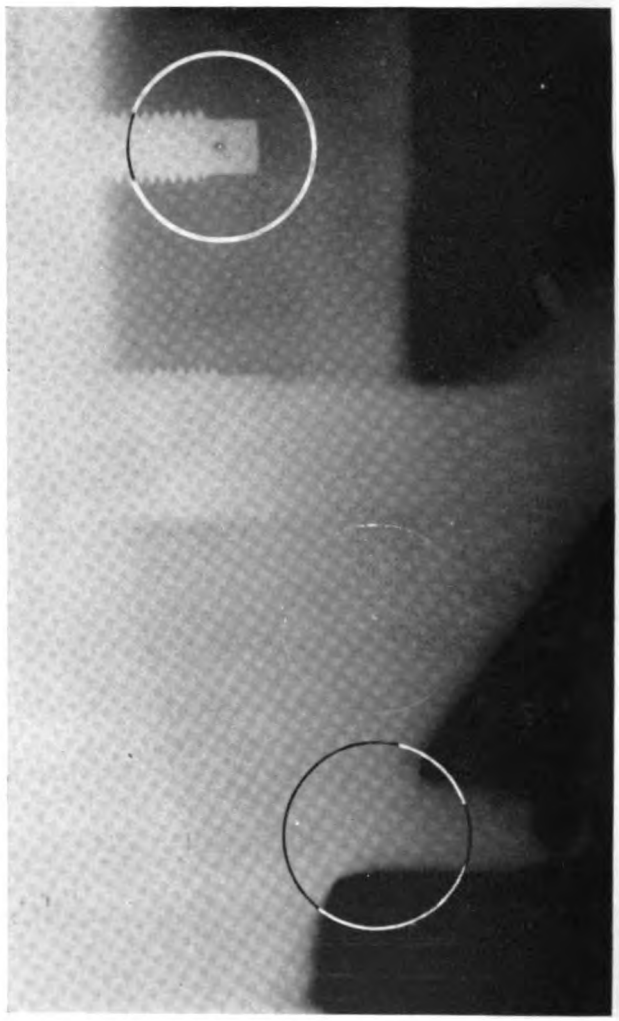


FIGURE 71. Aluminum Spots. Apparent porosity of sound aluminum casting; caused by Laue spots or diffraction of x-ray beam by metal; not apparent at higher voltages (this is 150 KV). Comparison of bolts will show this is not porosity

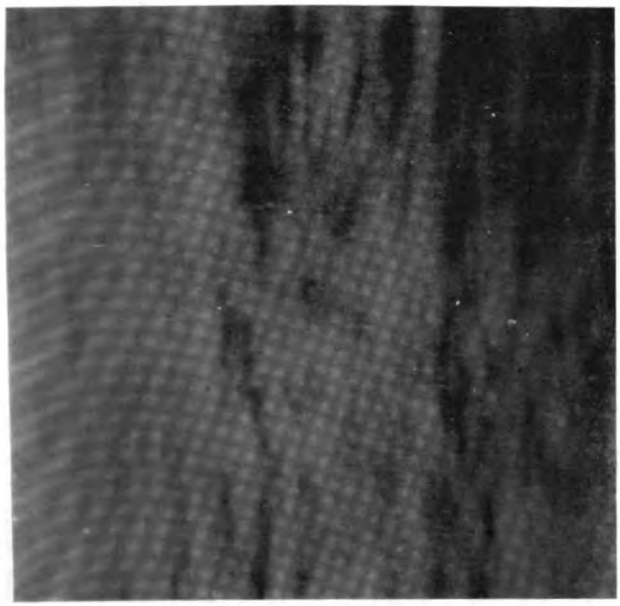


FIGURE 73. Mottle. Can be manufacturer's defect or caused in processing. When the latter, the pattern is larger

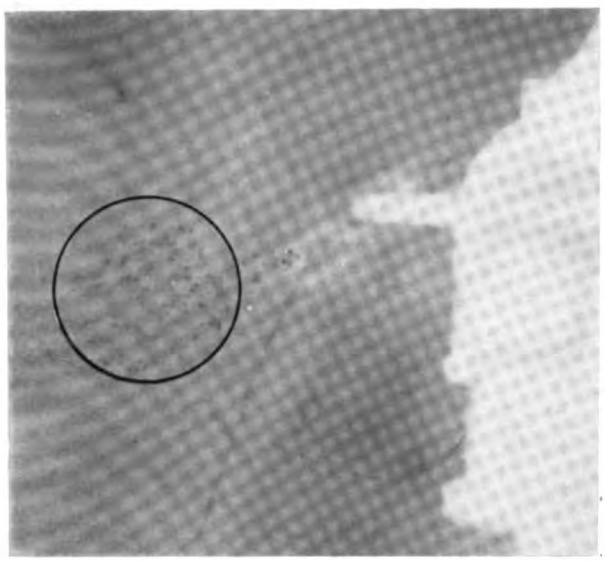


FIGURE 74. Moisture marks in lead holder. When films are left in holders overnight, moisture condensing on lead screens creates odd effects

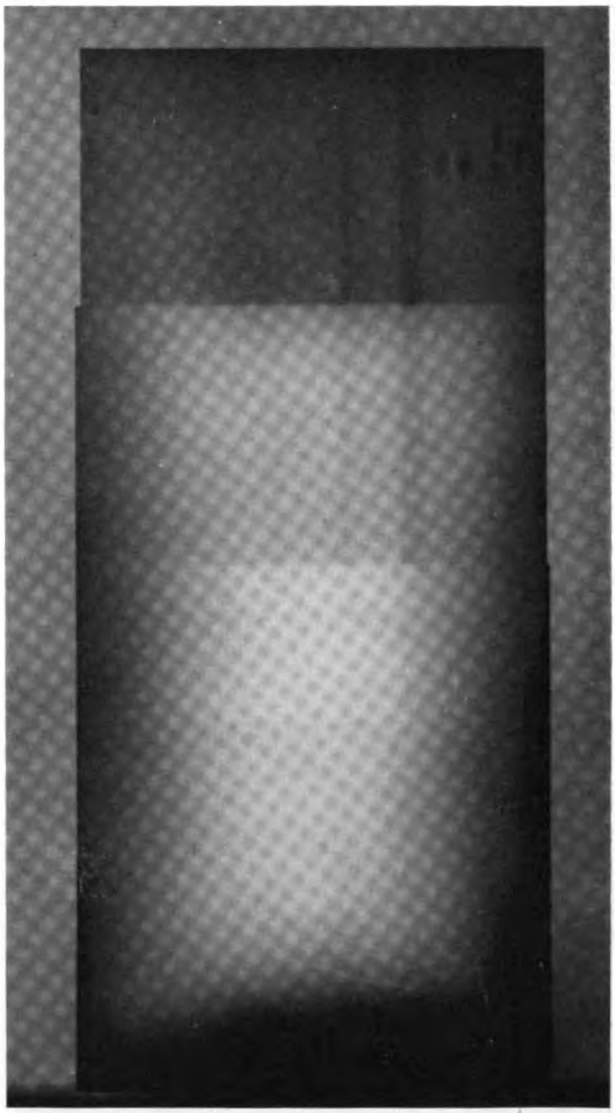


FIGURE 75. Reversal

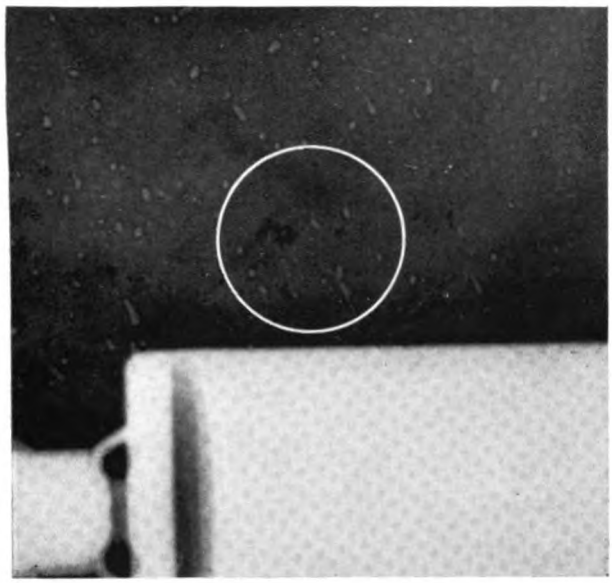


FIGURE 76. Water spots and surface spots

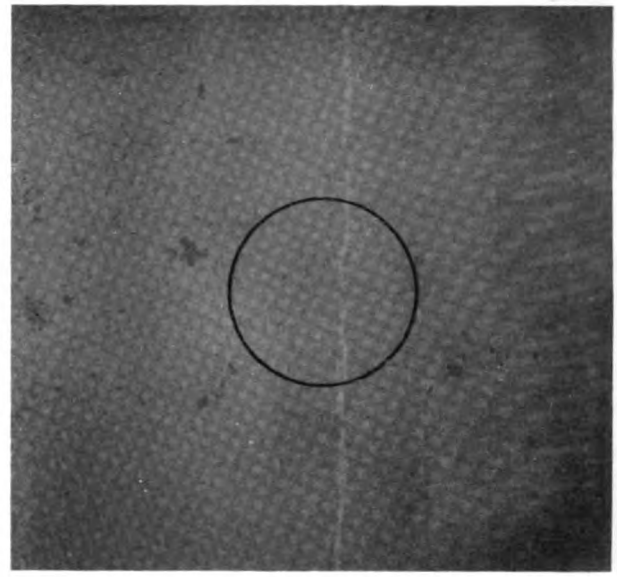


FIGURE 78. Manufacturer's defects. This is not caused by lead screens nor by scratching of holder clip

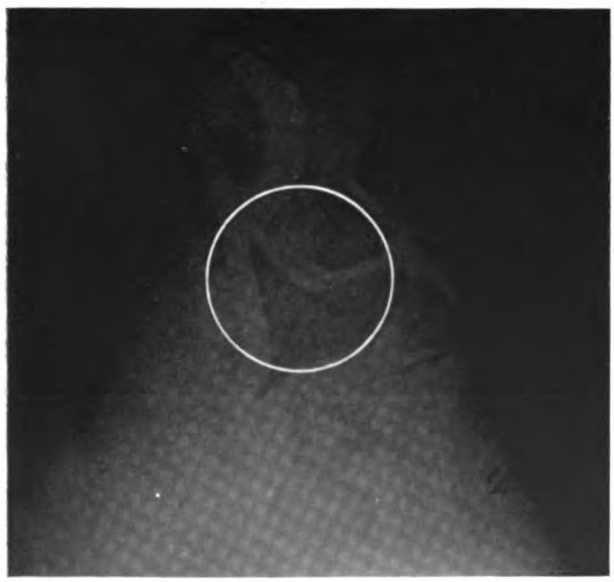


FIGURE 77. Developer scum

FIGURE 79

Chapter 9

RADIOGRAPHIC FACTORS AND TECHNIQUES

Exposure Factors

Given standard film processing, exposure necessary to produce a readable density on the film is dependent on several factors called "exposure factors." The factors are: voltage, current, exposure time, distance, and absorption.

The exposure time or intensity of radiation is an exponential function of the voltage. By actual measurement, the intensity, from 100 KV to 400 KV varies as shown in Figure 72. However, this relation changes at higher voltages, and the exponent approaches a value of three at 2 M.E.V. The shape of this curve varies with the thickness of the absorber also, owing to the heterogeneous beam.

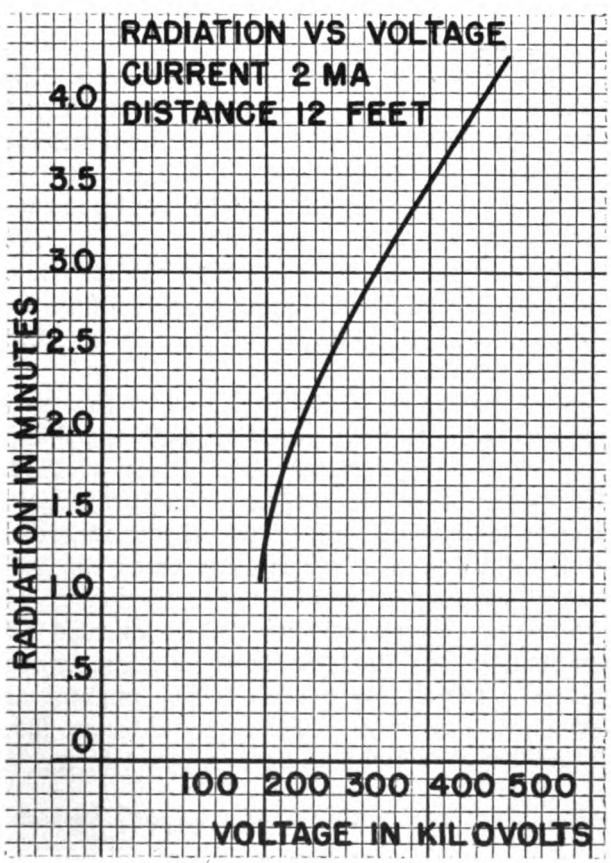


FIGURE 80

The intensity of radiation is the amount of radiation measured in Roentgens per minute. This is controlled by the current of the tube

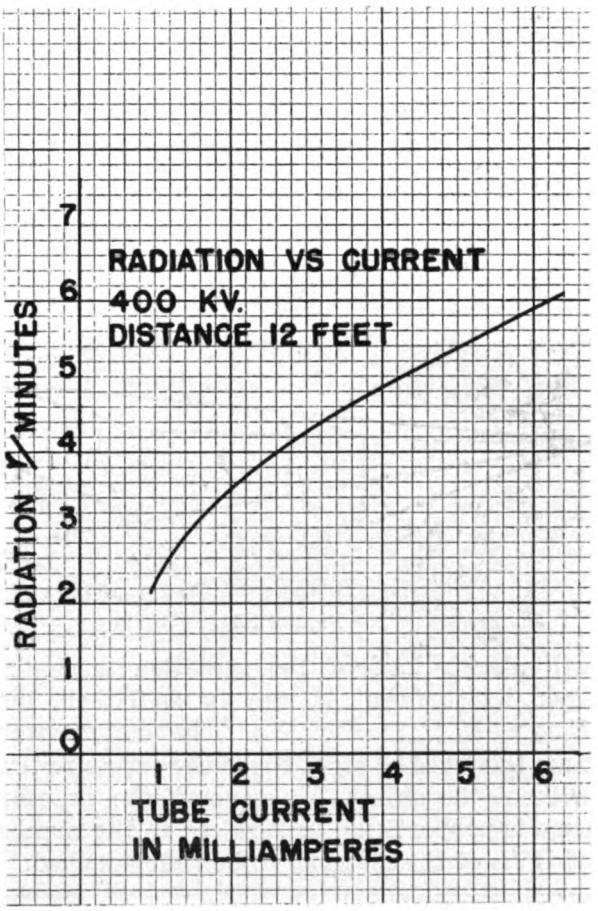


FIGURE 81

when measured at definite distance and voltage. The exposure time is inversely proportional to the current. Shown in Figure 81 is the radiation versus current curve. The shape of this curve is not a function of the absorber. This relation is always true and for practical purposes may be considered to be a straight line.

The exposure is directly proportional to the

square of the distance, as can be seen from Figure 82. This relation is always true.

Therefore, the exposure intensity is proportional to the current, proportional to a varying power X of the voltage and inversely proportional to the square of the distance.

$$I = K \frac{i \times V^x}{d^2}$$

where I = intensity, K = constant, i = current, V = voltage, d = distance

The film and screen combinations are listed separately in technique charts. Generally speaking, the greater the speed factor, the poorer the sensitivity; therefore, it is not always possible to use the fastest combination. The film and screen should be selected to meet the problem.

The density of the object is a limiting factor in radiography. It can best be stated by considering the half-value layers of the object. This means that if an object is equivalent to 3 HVL it has three thicknesses, each of which

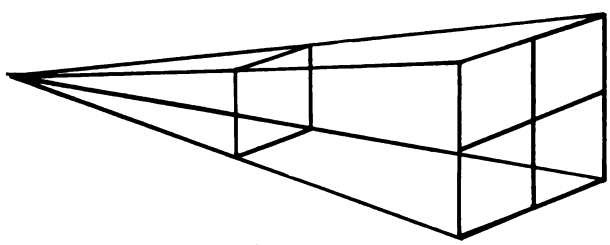


FIGURE 82

will absorb half of the radiation impinging upon its surface. It may be said then, that $E_{total} = E_o \times 2^3 = E_o \times 8$. The total exposure time then will be eight times the exposure time without the object. In general, the exposure time is proportional to 2 raised to the number of HVL of the material to be radiographed.

TABLE IV

HALF VALUE LAYER

Voltage	*Al*	*Fe*	*Cu*	*Pb*
150 KV	.75"	.045"	.036"	.010"
400 KV	1.5 "	.25 "	.10 "	.016"
2000 KV	2.30"	.85 "	.70 "	.53 "
Radium	2.5 "	.9 "	.75 "	.6 "

High Voltage Technique

In general differential masking is not used in radiography at higher voltages because of the greater latitude, obtained by the more penetrating short wave lengths. However, in cases of great variation in object thickness and density it is done to obtain a less contrasty radiograph. Masking is the process of placing a thickness of lead or equivalent over the thinner portions of the object that would be "burned cut" by exposure for a readable density in the thicker section.

In high voltage radiography it is considered good practice to place 1/8 inch lead over the film, to cut down on room scatter and forward scatter from the object. This lead is sometimes protected by a 1/32 inch stainless steel sheet to prevent the lead from being scratched.

Under the film is placed 1/2 inch of lead to eliminate the back scatter. The technician should be sure that the back lead and front lead completely cover the film.

The object or center point of the section should always be centered under the target by use of the plumb bob in order to reduce distortion in the radiograph. The object must be level in all directions.

When lead cones and inserts are used, the field of radiation and distance from target should be checked so that the film is not outside the beam.

The areas of radiation for different cone inserts, for varying target-film distances, are given in the accompanying chart, Figure 84.

When objects require more than one film the object must be sectionalized, that is, marked off into sections.

The amount of distortion due to the nonparallel paths of the photons through the thickness of the object cannot be entirely avoided. The radiograph is not then a true projection. The area near the top of the object recorded on the film is smaller than the area on the bottom of the object because of the divergence of the beam. Therefore the sections marked off are smaller than the film size and the films when viewed later should overlap. The amount of lap depends on object thickness and target film distance and is included here in chart form.

Instructions for High Voltage Layout System

I. Check file for photographs of subject.
   A. Objects radiographed before have

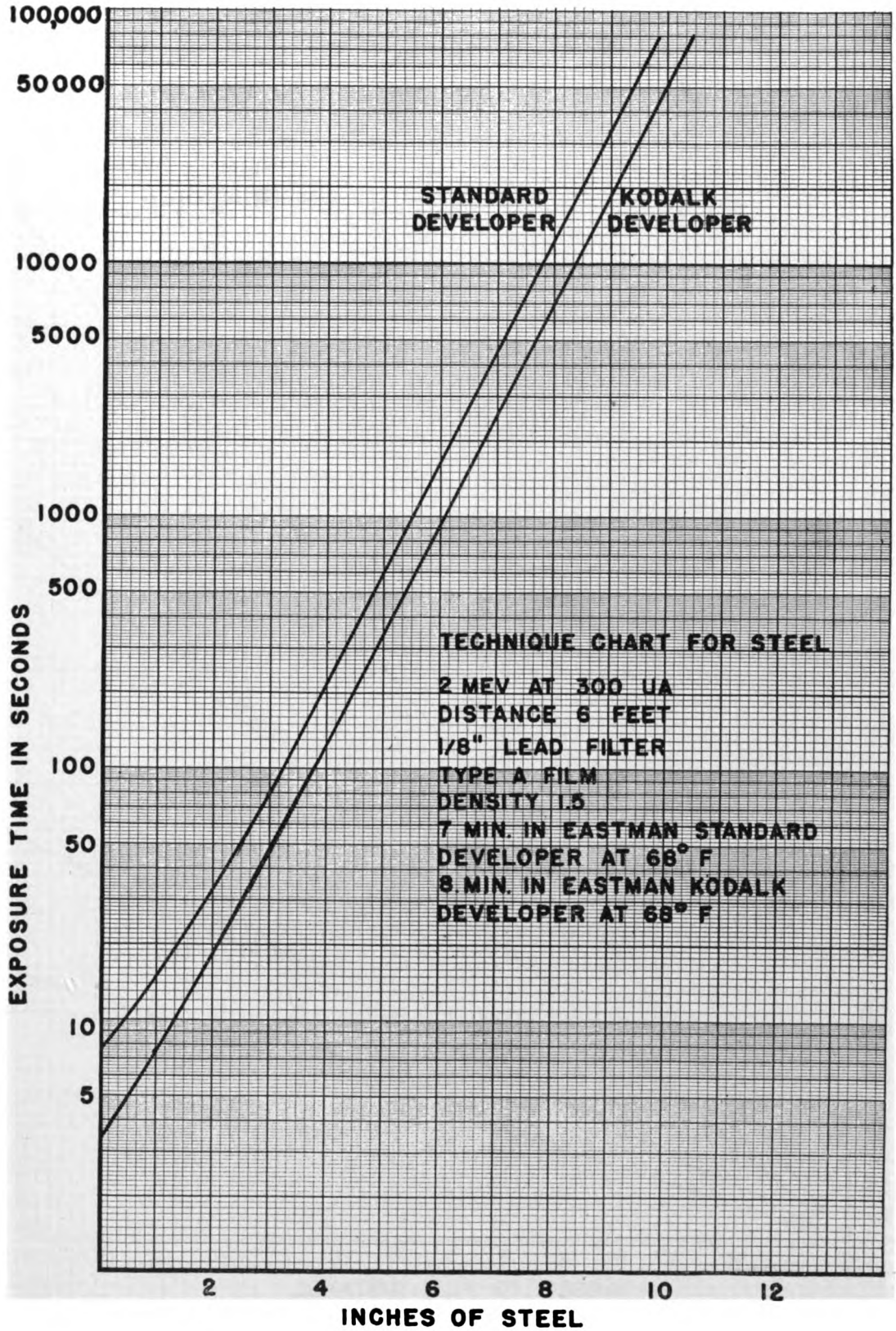


FIGURE 83

699810—46—5

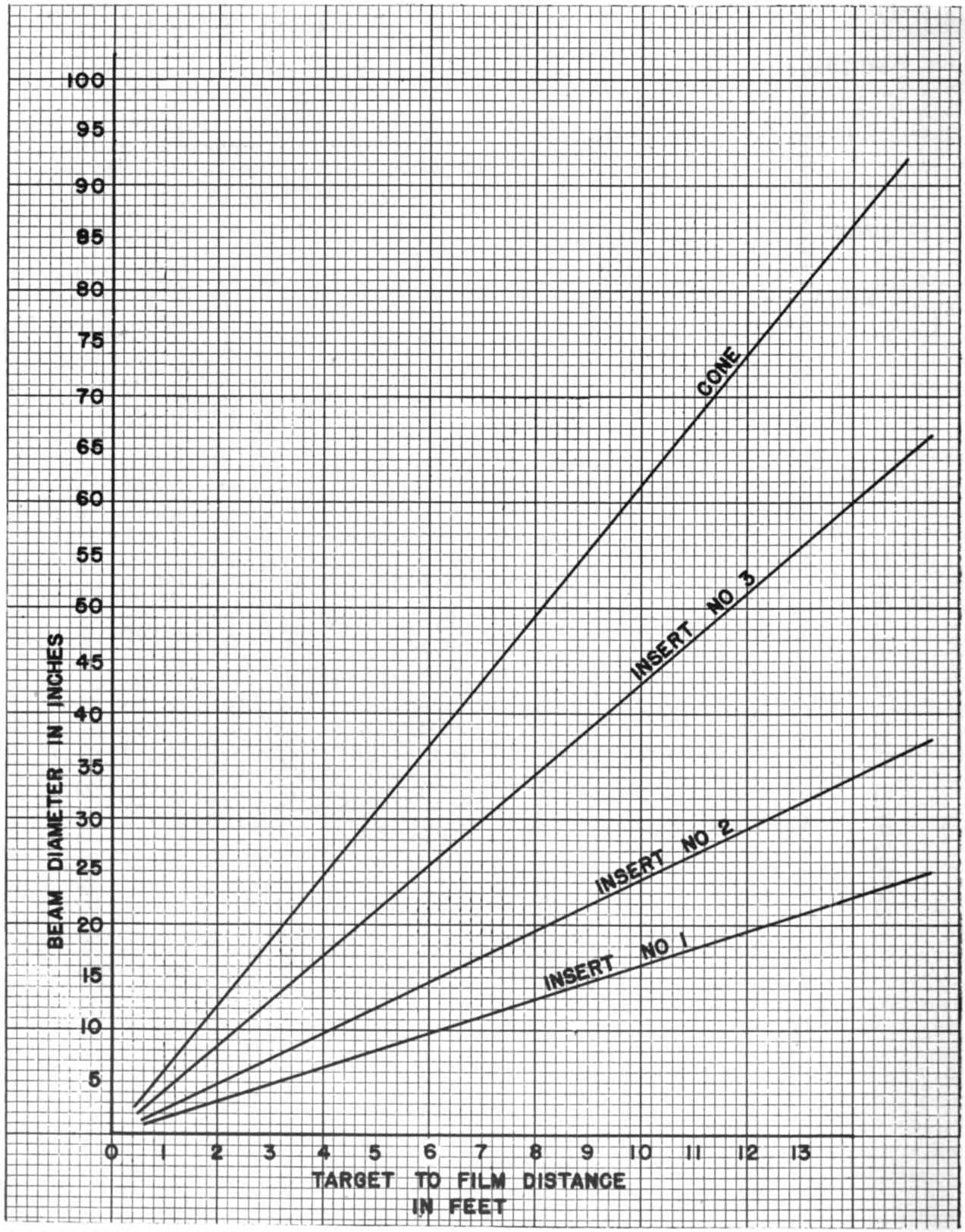


FIGURE 84. Van de Graaff Generator. Field of Radiation vs. Target to Film Distance for Cone Inserts

photographs that may be used on identical objects provided the layout is the same.

B. Photographs should be used to identify positions. Thus, by using identical positions on identical objects, the operator can eliminate photographing all but the first object.

II. Position 2 is 90° counterclockwise of Position I looking aft from nose.

III. The Lap.

A. Determine the width of lap from distortion chart.

1. It is desirable to use full inch lap only.
2. Example:
   a. T.f. distance—6 ft.

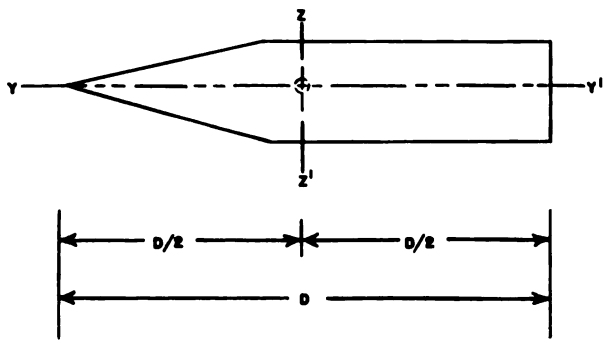


FIGURE 85

   b. Object maximum thickness—14 in.
   c. Film size—14 x 17 using the 14 in. under the maximum thickness.
   d. Chart reading—2.7 in.
   e. The lap is 3 in.

IV. The number of radiographs required for an entire object.

A. Use the formula $N = \frac{D}{W\text{-}L}$ to determine number of radiographs required.

1. D is *length* of object in inches.
2. L is width of *lap*.
3. W is *length of film* in inches along the center line.
4. N is *number of divisions* required.
5. Number of divisions required must be next larger whole number.
6. Example:
   D equals 80 in.
   W equals 14 in.
   L equals 4 in.

$\frac{D}{W\text{-}L}$ equals $\frac{80}{14\text{-}4}$ equals $\frac{80}{10}$ equals 8.

The number of film required is 8.

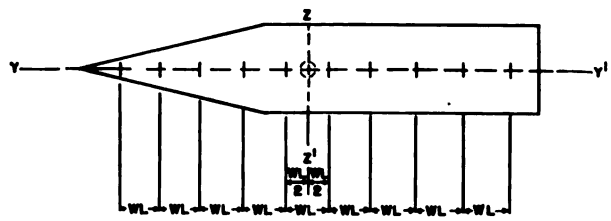


FIGURE 86

V. Sectionalizing an object.

A. To sectionalize objects, work from the center.

B. Laying out plumb points.

1. If the number of radiographs required is *EVEN:*
   a. The first plumb points on each side of the midpoint is a distance equal to one-half the effective length of the film along the center line $\frac{(W\text{-}L)}{2}$.
   b. All plumb points are along the center line (y-y^1).

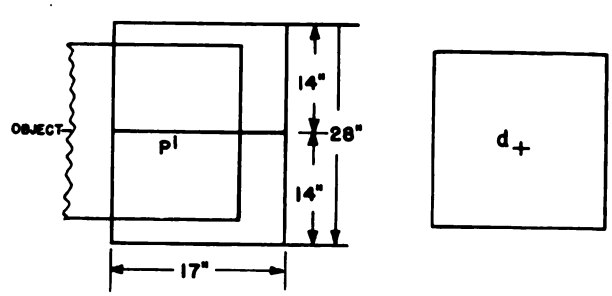


FIGURE 87

   c. All plumb points are spaced a distance equal to the length of the film along the center line less the width of the lap (W-L) apart.

2. If the number of radiographs required is an *ODD* number:
   a. The midpoint (O) is also the

plumb point of the center division or section.

b. All plumb points are along the center line (y-y^1)

c. All plumb points are spaced a distance equal to the effective length of the film along the center line (W-L) apart.

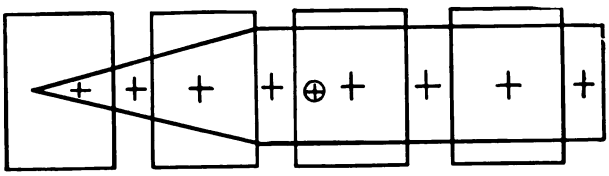


FIGURE 88

3. For objects too wide for one radiograph, use two radiographs; consider the two radiographs as one larger radiograph in laying out plumb points (P).

   EXAMPLE:

   a. Object is 21 in. wide.

   b. Required two 14 x 17 radiographs.

   c. Considered as one 17 x 28 radiograph.

4. Plumb points are in the center of the radiograph.

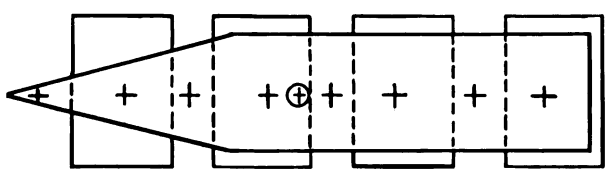


FIGURE 89

C. The border lines

1. Commencing at the nose the border line of the forward division is a solid line.

2. Every alternate or odd numbered division is bordered by solid lines.

3. The division adjoining the forward division is bordered by broken lines (- - - - -).

4. A- even number divisions are bordered by broken lines (- - - - -).

5. Miscellaneous sections are bordered by lines (- - - - -). (Note section's plumb point - - M.)

6. If the width of the object necessitates port and starboard radiographs, the center line is a solid line as in the above figure.

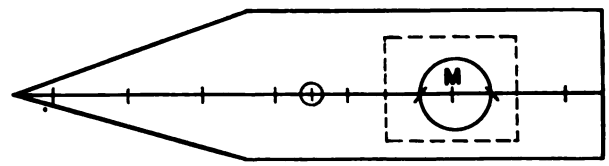


FIGURE 90

D. Numbering sections.

1. Number sections nose to stern.

2. Position 2 section numbers follow position 1 section numbers.

3. Numbers of miscellaneous sections follow position 2 section numbers.

4. If the width of the object necessitates port and starboard radiographs the even section numbers are always the port sections.

5. In removing film from holder insert film sideways, not endways. Then the film is in the same position as when exposed.

6. Film is numbered in upper right corner. Position and section numbers are placed in upper left corner.

7. The nose of the object points to the port side of the hoist platform (looking from the driver's seat).

TABLE V

LAP WIDTH: 10-INCH DISTORTION CHART

Target—Film Distance in Feet

Object Thickness in Inches	1	2	3	4	5	6	7	8	9	10	11	12
1	.8	.4	.3	.2	.2	.1	.1	.1	.1	.1	.1	.1
2	1.7	.8	.6	.4	.3	.3	.2	.2	.2	.2	.2	.1
3	2.5	1.3	.8	.6	.5	.4	.4	.3	.3	.3	.2	.2
4	3.3	1.7	1.1	.8	.7	.6	.5	.4	.4	.3	.3	.3
5	4.2	2.1	1.4	1.0	.8	.7	.6	.5	.5	.4	.4	.3
6	5.0	2.5	1.7	1.3	1.0	.8	.7	.6	.6	.5	.5	.4
7	...	2.9	1.9	1.5	1.2	1.0	.8	.7	.6	.6	.5	.5
8	...	3.3	2.2	1.7	1.3	1.1	1.0	.8	.7	.7	.6	.6
9	...	3.8	2.5	1.9	1.5	1.3	1.1	.9	.8	.8	.7	.6
10	...	4.2	2.8	2.1	1.7	1.4	1.2	1.0	.9	.8	.8	.7
11	...	4.6	3.1	2.3	1.8	1.5	1.3	1.1	1.0	.9	.8	.8
12	...	5.0	3.3	2.5	2.0	1.7	1.4	1.3	1.1	1.0	.9	.8
13	...	...	3.6	2.7	2.2	1.8	1.5	1.4	1.2	1.1	1.0	.9
14	...	...	3.9	2.9	2.3	1.9	1.7	1.5	1.3	1.2	1.1	1.0
15	...	...	4.2	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0
16	...	..	4.4	3.3	2.7	2.2	1.9	1.7	1.5	1.3	1.2	1.1
17	...	...	4.7	3.5	2.8	2.4	2.0	1.8	1.6	1.4	1.3	1.2
18	...	...	5.0	3.8	3.0	2.5	2.1	1.9	1.7	1.5	1.4	1.3
19	...	...	...	4.0	3.2	2.6	2.3	2.0	1.8	1.6	1.4	1.3
20	...	...	...	4.2	3.3	2.8	2.4	2.1	1.9	1.7	1.5	1.4
21	...	...	...	4.4	3.5	2.9	2.5	2.2	1.9	1.8	1.6	1.5
22	...	...	...	4.6	3.7	3.1	2.6	2.3	2.0	1.8	1.7	1.5
23	...	...	...	4.8	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6
24	...	...	...	5.0	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7
25	...	...	...	...	4.2	3.5	3.0	2.6	2.3	2.1	1.9	1.7
26	...	...	...	...	4.3	3.6	3.1	2.7	2.4	2.2	2.0	1.8
27	...	...	...	...	4.5	3.8	3.2	2.8	2.5	2.3	2.0	1.9
28	...	...	...	...	4.7	3.9	3.3	2.9	2.6	2.3	2.1	1.9
29	...	...	...	...	4.8	4.0	3.5	3.0	2.7	2.2	2.2	2.0
30	...	...	...	...	5.0	4.2	3.6	3.1	2.8	2.5	2.3	2.1
31	...	...	...	...	...	4.3	3.7	3.2	2.9	2.6	2.3	2.2
32	...	...	...	...	...	4.4	3.8	3.3	3.0	2.7	2.4	2.2
33	...	...	...	...	...	4.6	3.9	3.4	3.1	2.8	2.5	2.3
34	...	...	...	...	...	4.7	4.0	3.5	3.1	2.8	2.6	2.3
35	...	...	...	...	...	4.9	4.2	3.6	3.2	2.9	2.7	2.4
36	...	...	...	...	...	5.0	4.3	3.8	3.3	3.0	2.7	2.5

TABLE VI

LAP WIDTH: 12-INCH DISTORTION CHART

Target—Film Distance in Feet

Object Thickness in Inches	1	2	3	4	5	6	7	8	9	10	11	12
1	1.0	.5	.3	.3	.2	.2	.1	.1	.1	.1	.1	.1
2	2.0	1.0	.7	.5	.4	.3	.3	.3	.2	.2	.2	.2
3	3.0	1.5	1.0	.8	.6	.5	.4	.4	.3	.3	.3	.3
4	4.0	2.0	1.3	1.0	.8	.7	.6	.5	.4	.4	.4	.3
5	5.0	2.5	1.7	1.3	1.0	.8	.7	.6	.6	.5	.5	.4
6	6.0	3.0	2.0	1.5	1.2	1.0	.9	.8	.7	.6	.5	.5
7	...	3.5	2.3	1.8	1.4	1.2	1.0	.9	.8	.7	.6	.6
8	...	4.0	2.7	2.0	1.6	1.3	1.1	1.0	.9	.8	.7	.7
9	...	4.5	3.0	2.3	1.8	1.5	1.3	1.1	1.0	.9	.8	.8
10	...	5.0	3.3	2.5	2.0	1.7	1.4	1.3	1.1	1.0	.9	.8
11	...	5.5	3.7	2.8	2.2	1.8	1.6	1.4	1.2	1.1	1.0	.9
12	...	6.0	4.0	3.0	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0
13	...	...	4.3	3.3	2.6	2.2	1.9	1.6	1.4	1.3	1.2	1.1
14	...	...	4.7	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.3	1.2
15	...	...	5.0	3.8	3.0	2.5	2.1	1.9	1.7	1.5	1.4	1.3
16	...	...	5.3	4.0	3.2	2.7	2.3	2.0	1.8	1.6	1.5	1.3
17	...	...	5.7	4.3	3.4	2.8	2.4	2.1	1.9	1.7	1.5	1.4
18	...	...	6.0	4.5	3.6	3.0	2.6	2.3	2.0	1.8	1.6	1.5
19	...	..	...	4.8	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6
20	...	..	...	5.0	4.0	3.3	2.9	2.5	2.2	2.0	1.8	1.7
21	...	...	...	5.3	4.2	3.5	3.0	2.6	2.3	2.1	1.9	1.8
22	...	...	...	5.5	4.4	3.7	3.1	2.8	2.4	2.2	2.0	1.8
23	...	...	...	5.8	4.6	3.8	3.3	2.9	2.6	2.3	2.1	1.9
24	...	...	...	6.0	4.8	4.0	3.4	3.0	2.7	2.4	2.2	2.0
25	...	...	...	...	5.0	4.2	3.6	3.1	2.8	2.5	2.3	2.1
26	...	...	...	...	5.2	4.3	3.7	3.3	2.9	2.6	2.4	2.2
27	...	...	...	...	5.4	4.5	3.9	3.4	3.0	2.7	2.5	2.3
28	...	...	...	...	5.6	4.7	4.0	3.5	3.1	2.8	2.5	2.3
29	...	...	...	...	5.8	4.8	4.1	3.6	3.2	2.9	2.6	2.4
30	...	...	...	...	6.0	5.0	4.3	3.8	3.3	3.0	2.7	2.5
31	...	...	...	...	...	5.2	4.4	3.9	3.4	3.1	2.8	2.6
32	...	...	...	...	...	5.3	4.6	4.0	3.6	3.2	2.9	2.7
33	...	...	...	...	...	5.5	4.7	4.1	3.7	3.3	3.0	2.8
34	...	...	...	...	...	5.7	4.9	4.3	3.8	3.4	3.1	2.8
35	...	...	...	...	...	5.8	5.0	4.4	3.9	3.5	3.2	2.9
36	...	...	...	...	...	6.0	5.1	4.5	4.0	3.6	3.3	3.0

TABLE VII

LAP WIDTH: 14-INCH DISTORTION CHART

Target—Film Distance in Feet

Object Thickness in Inches	1	2	3	4	5	6	7	8	9	10	11	12
1	1.2	.6	.4	.3	.2	.2	.2	.1	.1	.1	.1	.1
2	2.3	1.2	.8	.6	.5	.4	.3	.3	.3	.2	.2	.2
3	3.5	1.8	1.2	.9	.7	.6	.5	.4	.4	.4	.3	.3
4	4.7	2.3	1.6	1.2	.9	.8	.7	.6	.5	.5	.4	.4
5	5.8	2.9	1.9	1.5	1.2	1.0	.8	.7	.6	.6	.5	.5
6	7.0	3.5	2.3	1.8	1.4	1.2	1.0	.9	.8	.7	.6	.6
7	...	4.1	2.7	2.0	1.6	1.4	1.2	1.0	.9	.8	.7	.7
8	...	4.7	3.1	2.3	1.9	1.6	1.3	1.2	1.0	.9	.8	.8
9	...	5.3	3.5	2.6	2.1	1.8	1.5	1.3	1.2	1.1	1.0	.9
10	...	5.8	3.9	2.9	2.3	1.9	1.7	1.5	1.3	1.2	1.1	1.0
11	...	6.4	4.3	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.2	1.1
12	...	7.0	4.7	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.3	1.2
13	...	...	5.1	3.8	3.0	2.5	2.2	1.9	1.7	1.5	1.4	1.3
14	...	...	5.4	4.1	3.3	2.7	2.3	2.0	1.8	1.6	1.5	1.4
15	...	...	5.8	4.4	3.5	2.9	2.5	2.2	1.9	1.8	1.6	1.5
16	...	..	6.2	4.7	3.7	3.1	2.7	2.3	2.1	1.9	1.7	1.6
17	...	...	6.6	5.0	4.0	3.3	2.8	2.5	2.2	2.0	1.8	1.7
18	...	...	7.0	5.3	4.2	3.5	3.0	2.6	2.3	2.1	1.9	1.8
19	...	...	...	5.5	4.4	3.7	3.2	2.8	2.5	2.2	2.0	1.8
20	...	...	...	5.8	4.7	3.9	3.3	2.9	2.6	2.3	2.1	1.9
21	...	...	...	6.1	4.9	4.1	3.5	3.1	2.7	2.5	2.2	2.0
22	...	...	...	6.4	5.1	4.3	3.7	3.2	2.9	2.6	2.3	2.1
23	...	...	...	6.7	5.4	4.5	3.8	3.4	3.0	2.7	2.4	2.2
24	...	...	...	7.0	5.6	4.7	4.0	3.5	3.1	2.8	2.5	2.3
25	...	...	...	...	5.8	4.9	4.2	3.6	3.2	2.9	2.7	2.4
26	...	...	...	...	6.1	5.1	4.3	3.8	3.4	3.0	2.8	2.5
27	...	...	...	...	6.3	5.3	4.5	3.9	3.4	3.2	2.9	2.6
28	...	...	...	...	6.5	5.4	4.7	4.1	3.6	3.3	3.0	2.7
29	...	...	...	...	6.8	5.6	4.8	4.2	3.8	3.4	3.1	2.8
30	...	...	...	...	7.0	5.8	5.0	4.4	3.9	3.5	3.2	2.9
31	...	...	...	...	...	6.0	5.2	4.5	4.0	3.6	3.3	3.0
32	...	...	...	...	...	6.2	5.3	4.7	4.1	3.7	3.4	3.1
33	...	...	...	...	...	6.4	5.5	4.8	4.3	3.9	3.5	3.2
34	...	...	...	...	...	6.6	5.7	5.0	4.4	4.0	3.6	3.3
35	...	...	...	...	...	6.8	5.8	5.1	4.5	4.1	3.7	3.4
36	...	...	...	...	...	7.0	6.0	5.3	4.7	4.2	3.8	3.5

TABLE VIII

Lap Width: 17-Inch Distortion Chart

Target—Film Distance in Feet

Object Thickness in Inches	1	2	3	4	5	6	7	8	9	10	11	12
1	1.4	.7	.5	.4	.3	.2	.2	.2	.2	.1	.1	.1
2	2.8	1.4	.9	.7	.6	.5	.4	.4	.3	.3	.3	.2
3	4.3	2.1	1.4	1.1	.9	.7	.6	.5	.5	.4	.4	.4
4	5.7	2.8	1.9	1.4	1.1	.9	.8	.7	.6	.6	.5	.5
5	7.1	3.5	2.4	1.8	1.4	1.2	1.0	.9	.8	.7	.6	.6
6	8.5	4.3	2.8	2.1	1.7	1.4	1.2	1.1	.9	.9	.8	.7
7	..	5.0	3.3	2.5	2.0	1.7	1.4	1.2	1.1	1.0	.9	.8
8	...	5.7	3.8	2.8	2.3	1.9	1.6	1.4	1.3	1.1	1.0	.9
9	..	6.4	4.3	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.2	1.1
10	...	7.1	4.7	3.5	2.8	2.4	2.0	1.8	1.6	1.4	1.3	1.2
11	...	7.8	5.2	3.9	3.1	2.6	2.2	1.9	1.7	1.6	1.4	1.3
12	...	8.5	5.7	4.3	3.4	2.8	2.4	2.1	1.9	1.7	1.5	1.4
13	...	...	6.1	4.6	3.7	3.2	2.6	2.3	2.0	1.8	1.7	1.5
14	...	...	6.6	5.0	4.0	3.3	2.8	2.5	2.2	2.0	1.8	1.7
15	...	...	7.1	5.3	4.3	3.5	3.0	2.7	2.4	2.1	1.9	1.8
16	...	...	7.6	5.7	4.5	3.8	3.2	2.8	2.5	2.3	2.1	1.9
17	...	...	8.0	6.0	4.8	4.0	3.4	3.0	2.7	2.4	2.2	2.0
18	...	...	8.5	6.4	5.1	4.3	3.6	3.2	2.8	2.6	2.3	2.1
19	...	..	...	6.7	5.4	4.5	3.8	3.4	3.0	2.7	2.4	2.2
20	...	..	...	7.1	5.7	4.7	4.0	3.5	3.1	2.8	2.6	2.4
21	...	...	...	7.4	6.0	5.0	4.3	3.7	3.3	3.0	2.7	2.5
22	...	..	...	7.8	6.2	5.2	4.5	3.9	3.5	3.1	2.8	2.6
23	...	..	...	8.1	6.5	5.4	4.7	4.1	3.6	3.3	3.0	2.7
24	...	...	..	8.5	6.8	5.7	4.9	4.3	3.8	3.4	3.1	2.8
25	...	..	...	...	7.1	5.9	5.1	4.4	3.9	3.5	3.2	3.0
26	...	..	...	..	7.4	6.1	5.3	4.6	4.1	3.7	3.3	3.1
27	...	...	...	...	7.7	6.4	5.5	4.8	4.3	3.8	3.5	3.2
28	...	...	...	...	7.9	6.6	5.7	5.0	4.4	4.0	3.6	3.3
29	...	..	...	...	8.2	6.8	5.9	5.1	4.6	4.1	3.7	3.4
30	...	...	...	..	8.5	7.1	6.1	5.3	4.7	4.3	3.9	3.5
31	...	..	...	...	...	7.3	6.3	5.5	4.9	4.4	4.0	3.7
32	...	..	...	...	...	7.6	6.5	5.7	5.0	4.5	4.1	3.8
33	...	...	..	...	...	7.8	6.7	5.8	5.2	4.7	4.3	3.9
34	...	..	...	...	...	8.0	6.9	6.0	5.4	4.8	4.4	4.0
35	...	...	...	...	...	8.3	7.1	6.2	5.5	5.0	4.5	4.1
36	...	..	...	...	...	8.5	7.3	6.4	5.7	5.1	4.6	4.3

TABLE IX

CALCULATED BEAM DIAMETERS

Target-Film	*Cone Insert Numbers*			
Distance	#1	#2	#3	No Insert
1	1.6	2.4	4.3	6.2
2	3.2	4.8	8.6	12.4
3	4.8	7.2	12.9	18.6
4	6.4	9.6	17.2	24.8
5	8.0	12.0	21.6	31.
6	9.6	14.4	25.9	37.2
7	11.2	16.8	30.2	43.4
8	12.8	19.2	34.5	49.6
9	14.4	21.6	38.8	55.8
10	16.0	24.0	43.2	62.
11	17.6	26.4	47.5	68.2
12	19.2	28.8	51.8	78.6
12′ 6″	20.6	30.4	54.7	78.6

Exposure Factors and Techniques—Low Voltage

Conversion Tables for Film and Screen Speeds

Frequently it is helpful to know the relative exposure factors for different films and screens. One single chart cannot be made because of the effect of different kilovoltages on screens, the changing speed factors of film at different densities, and the changing of the quality of the radiation due to filtration of different object densities.

Following is a table showing the average exposure factors at 400 KV, density of 1.5 Standard Development based on "A" film in lead screens.

TABLE X

Type Film	*Screens*	*Exposure Factor*
"F"	#245	0.60
Ansco "HS"	#245	0.65
"K"	Pb	25.
"F"	Pb	60.
Ansco "HS"	Pb	65.
"A"	Pb	100.
Super Ray "A"	Pb	140.
Super Ray "B"	Pb	150.
"M"	Pb	300.

The above factors in lead screens should be tripled when using plain holders with an object thickness of 1″ of steel at 400 KV. At 150 KV, the above factors are correct except for the #245 screens which should be halved. At 150 KV when using plain holders with an object thickness of ½″ of steel, the factor is the same as for Pb screens. At 2000 KV and with gamma radiation the factors with #245 screens should be doubled.

Actual Setup—Low Voltage

The procedure varies somewhat in the use of the different machines. Some radiographs are made with the plane of the film in a vertical position and the machine "shooting" horizontally. Others are made with the film in a horizontal position and the machine "shooting" down vertically. In either case the line of radiation should strike the center of the film perpendicular to the plane of the film.

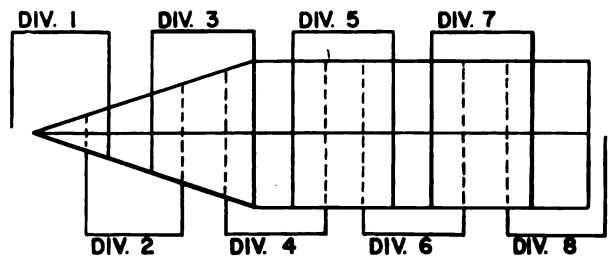


FIGURE 91

The center of the film is determined by use of a plumb bob when the tube is over the film. In the case of the 400 KV G.E. unit when "shooting" horizontally, the centering is done by sighting along lines painted on the sides and top of the cone. Photographs are included to show the usual setup. The plane of the film can be made perpendicular to the line of radiation in case of a horizontal beam by sighting along a carpenter's square placed at the center of the film.

The film holder should be backed up by sheet lead of at least 1/16 inch thickness to absorb the back scatter from walls, floors, etc. This is especially important when radiographing thicker sections and when using calcium tungstate screens. The back scatter is evidenced by white streaks on the film under the cassette back straps.

If small enough, the object should be centered on the film. The centering is usually done by blocking up the object.

If the object is too long to get on one film it will have to be sectionalized. The usual system is to number the sections consecutively

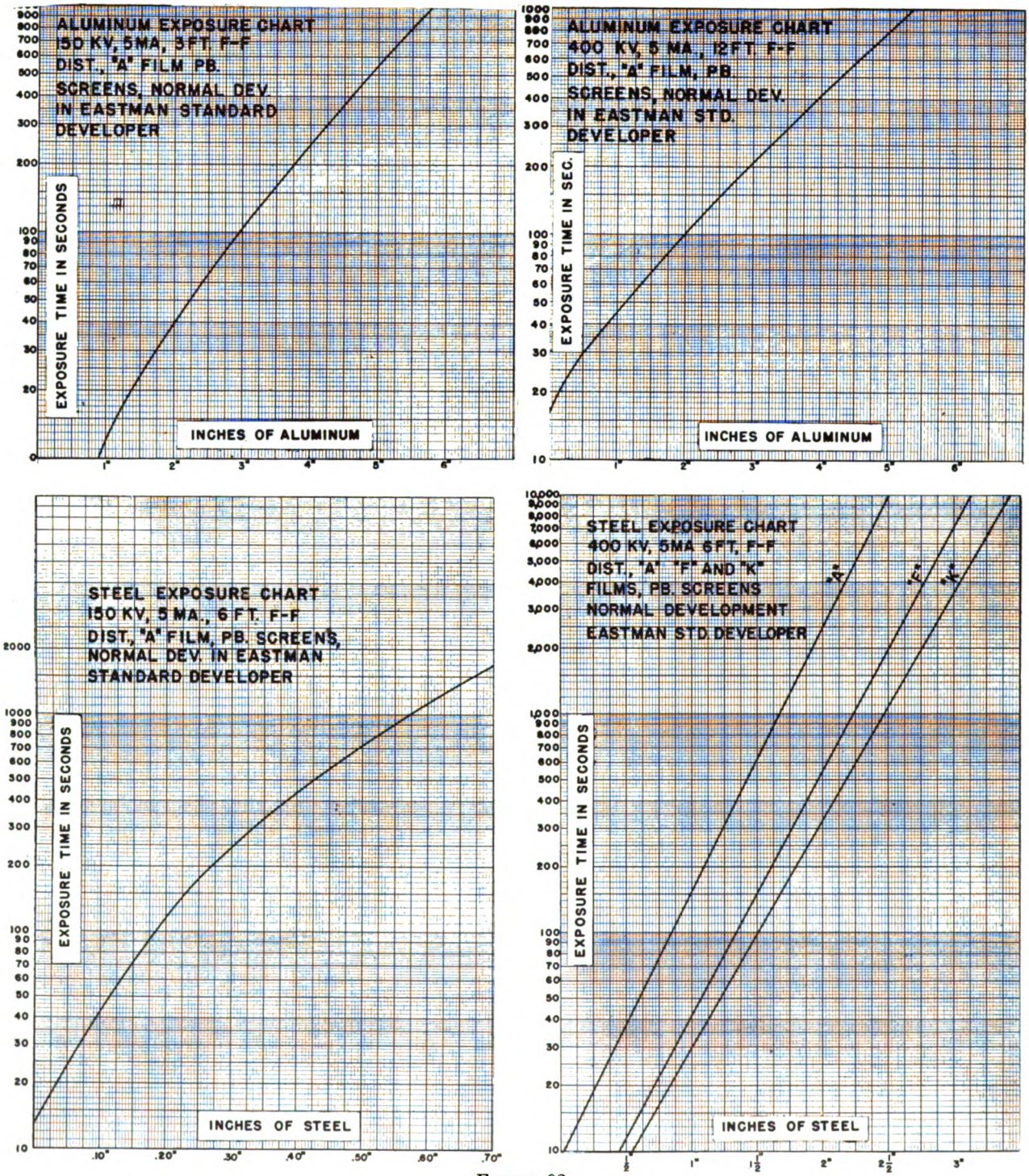


FIGURE 92

from left to right or from nose to base of the object. An inch overlap is usually sufficient between films, and any overlap of the ends should be equalized on the end films.

In a large number of cases the object has to be rotated through 90 degrees for a second radiograph. In the case of some small objects both views may be put on one film by blocking

or masking one half of the film with lead plates. For the 150 KV unit one ⅜ inch lead plate should be used; for the 400 KV unit, three ⅜ inch plates. The object is rotated in a counterclockwise direction (looking forward) for the 90 degree radiograph.

In some cases there may be some doubt as to which x-ray machine to select. For best results with anything equivalent to ½ inch of steel or less use the 150 KV unit; for ½ inch to 1 inch of steel, the 250 KV unit; for 1 to 2 inches of steel, the 400 KV unit; and for anything above this use either the radium or 2000 KV unit. In some special cases the medical unit which has a range from 20 to 40 KV may be used when the object is not over the equivalent of a few millimeters of aluminum in thickness.

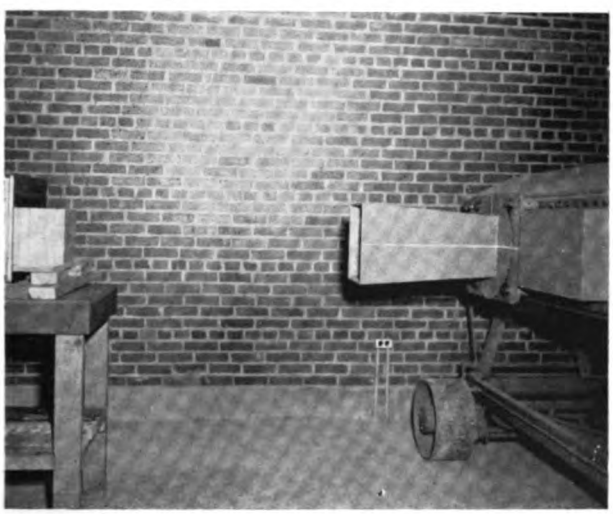


FIGURE 93. Setup for 400 KV

A photograph should be made of any radiographic setup, the radiographs of which are to be used in a report. If the photograph is not made at the time of the taking of the radiograph particular care should be taken that all details are the same in the radiograph and photograph.

Identification

Some system has to be employed for identifying the radiographs.

a. In low voltage radiography the usual system is the use of lead letters and numbers which should be placed in the upper right-hand corner if possible. In some cases it will be necessary to place sheet lead behind the numbers to prevent their being "burned out."

b. In some cases the numbers may have to be stamped in the radiograph after processing, in which case the numbers should be stamped in the upper right-hand corner.

Filters

Filters as used in industrial radiography are usually made of sheet lead but in special cases they are made of other materials having a high absorption. They are used in addition to and frequently with ordinary lead filter screens and are especially important when radiographing dense objects at low kilovoltages with calcium tungstate screens.

a. They are used in some cases at the tube to absorb the longer wave length radiation. When used in this way the beam of radiation in being hardened, increases the film latitude. The reason for the increased latitude is a smaller percentage of absorption of the rays when impinging upon the thicker object sections.

b. When the object is cylindrically or irregularly shaped, filters are used between the object and film to reduce the "undercut" caused by scattered radiation. In addition to absorbing scatter, the filter in this position increases latitude as explained in the preceding paragraph.

c. In some cases the difference in densities of portions of an object are so great that a filter of the proper thickness will have to be used under only the thinner sections to equalize film density or to bring it into a viewable range. These filters or masks are made up of lead sheet, special high density solutions in which the object is immersed, fine copper shot, or special plastic compounds.

d. In order to prevent "undercut," frequently a mask is made of lead or special plastic masking compound which outlines the object and allows only that radiation which penetrates the object to strike the film.

e. A Bucky grid is frequently used to filter out or absorb scatter. It is composed of thin strips of lead assembled in a grid or plate. The grid is perpendicular to and the planes of the strips are parallel to the lines of radiation. This grid is used between the object and film to ab-

sorb the angular scatter but allows the parallel direct radiation to pass through the spaces in the grids. In order to prevent grid lines showing in the film, the grid is usually oscillated or otherwise moved during exposure.

f. Frequently there is considerable back scattered radiation from walls, floors and other objects. This back scatter is quite evident when radiographing heavy sections with calcium tungstate screens and causes the film to be darkened except for those areas under the back straps. The usual way of preventing this is to back the cassette or film holder with a sheet of lead. With low voltage machines, a 1/16 inch sheet of lead has been found sufficient for this purpose.

One other way of preventing "scatter" from reaching the film is through the use of cones at the source of radiation. These limit the size of the field of radiation to the area of the film. Actually a greater benefit can be obtained from the use of a cone if it limits the field of radiation to the object area.

Chapter 10

RADIUM

Discovery and History

In 1896 it was discovered that uranium salts emitted radiation capable of penetrating large thicknesses and affecting sensitive photographic emulsions. It was also found that the radiation from uranium salts did not exactly follow in proportion to the amount of the material, and upon further investigation, especially by the Curies, radium and other radioactive substances were discovered.

These radioactive elements are extracted from pitch-blende ore, which is found in various places but at present is obtained mainly from Canada, where rich deposits have been located.

Theory of Gamma Ray Production

Radioactive substances are characterized by the spontaneous emission of particles and radiation upon nuclear disintegration of the substances.

The emitted particles are known as alpha- and beta-particles or rays. The radiation is known as gamma-rays. The alpha-particles are positively charged and have been identified as the nuclei of helium atoms, each having twice the charge of a proton and a mass number of four. Alpha rays are absorbed in a few centimeters of air.

The negatively charged beta-particles emitted by radioactive substances have been identified as electrons, each having a mass depending on its speed and having one unit of negative charge. It has been found that beta-particles are of two types: (1) electrons emitted from the nucleus and (2) electrons ejected from the electronic energy levels of the atom by the gamma rays; these are known as conversion electrons. Beta-particles are absorbed by a few centimeters of aluminum.

Gamma rays are not emitted by all radioactive substances but their emission is always accompanied by the emission of alpha- or beta-particles. It is not understood exactly how gamma rays are emitted. It is assumed and borne out partially by experiment that those atoms which emit high energy alpha- or beta-particles have a stable nucleus and do not emit gamma radiation, while the nuclei of those atoms which lose a lower energy particle emit gamma radiation with an energy equal to the difference in energies of the high and lower energy alpha- or beta-particles.

When emitted gamma rays eject conversion electrons from their energy levels, there will be an emission of characteristic radiation upon the replacement of the electrons. This effect accounts for the softer radiation given off by any radioactive source.

Gamma ray wave lengths vary from .233 Angström (53.7 electron KV) to .00561 Angström (2,240 electron KV). The effective wave length is in the neighborhood of .012 Angström (1030 electron KV) or roughly the same as that produced by a 1350 KV x-ray machine.

Gamma ray out-put of radium in roentgens

$$(r) = \frac{\text{mg} \times \text{hr.} \times 8}{(\text{dist. in cm.})^2}$$

The radiation from one gram of radium is said to be one "curie" but is usually expressed in millicuries.

Table of Disintegration and Half Life

The total life of radioactive substances is not easily measured. The usual method of expressing the lives of these substances is the half life value, this is the length of time required for the substance to lose half of its activity.

Gammagraphy

The radium source used by the Ordnance Investigation Laboratory is 2000 milligrams per unit. The radium is soldered in four 500-milligram silver capsules. The four capsules are stacked, one behind the other; all four are enclosed in a split sleeve which is inserted in a hollow aluminum cone. The cone is backed up by a 3-inch long cylinder of lead and both are

secured in a brass sleeve. This cylinder containing the radium is used for the radiography and is placed in an adjustable trough which can be secured to an ordinary photographic tripod or a rod driven into the ground. When not in use the cylinder is placed in a 3-inch lead lined brass pot for storage and transportation.

The portable radium unit is composed of the radium pot, weighing about 100 pounds, and two boxes each 48″ by 18″ by 18″, containing film, chemicals, developing trays, dark room tent, and other necessary articles. The whole unit weighs about 400 pounds.

In making the actual exposure set-up it should be remembered that the plane of the film must be centered with and perpendicular to the beam of radiation. The film, radium cylinder holder, and filter if used, should all be set up first, and the radium last to avoid exposure to operating personnel.

TABLE XI

RADIOACTIVE MATERIALS USEFUL FOR INDUSTRIAL RADIOGRAPHY

(Those available in commercial quantities have been underscored)

Symbol	*Name*	*Atomic Number*	*Atomic Weight*	*Radiation*	*Half Period, T*	*Remarks*
Ra	*Radium*	88	225.97	α	1580 years	Gamma-rays due to products Ra B, Ra C, Ra D, and Ra E
Rn	*Radon*	86	(222)	α	3.8 days	The same. Can be pumped off from radium solutions
Ra A	Radium A	84	(218)	α	3.05 min.	
Ra B	Radium B	82	(214)	β and γ	26.8 min.	Principal source of useful gamma-rays
Ra C	Radium C	83	(214)	β and γ	19.7 min.	
Ra C′	Radium C′	84	(214)	α	About 10^{-6} sec.	
Ra D	Radium D	82	(210)	β and γ	About 16.5 years	
Ra E	Radium E	83	(210)	β and γ	5 days	
Ra F	Radium F	84	(210)	α	136 days	
Ra G	Radium G	82	206.05	Stable		Known as "uranium lead"

Determination of Exposure

Exposure time may be determined by one of several methods: (1) by reference to charts, (2) by use of a slide rule, or (3) by calculation of half-value layers.

1. The use of charts is quite simple, since the objects to be radiographed consists chiefly of explosive, aluminum, and steel. There would have to be either three curves for these different materials or one for steel and a conversion chart for the other materials.

To use the exposure chart (a) read the thickness on the bottom line, (b) move vertically to the diagonal line representing the radium film distance, and (c) read the exposure time at the left.

To use the conversion chart (a) read the thickness of the material at the left, (b) move horizontally to the diagonal for the material at that value, and (c) read the equivalent thickness of steel at the bottom.

2. In using the slide rule, (a) set the distance in feet on the slide to the total number of half-value layers, and (b) read the exposure time in minutes on the scale opposite the arrow on the slide corresponding to the film and screen combination used.

3. The method of determining exposure by calculation of half-value layers is a rough method that eliminates reference to charts.

One half-value layer is the thickness of a given material required to reduce the intensity of a beam of gamma-ray radiation by one-half. With radium, the half-value layer for steel is 0.9 inch. This means that 0.9 inch of steel will reduce the intensity of the radiation to one-half of its original intensity. In terms of film density twice the time of exposure is required to

produce the same density on the film, if 0.9 inch of steel is placed in the path of the beam.

It has been determined that an exposure of 30 seconds with 2000 milligrams of radium at 36 inch radium-film distance with no filter between the radium and the film will produce a density of one on type F film with calcium-tungstate screens if the film is developed in

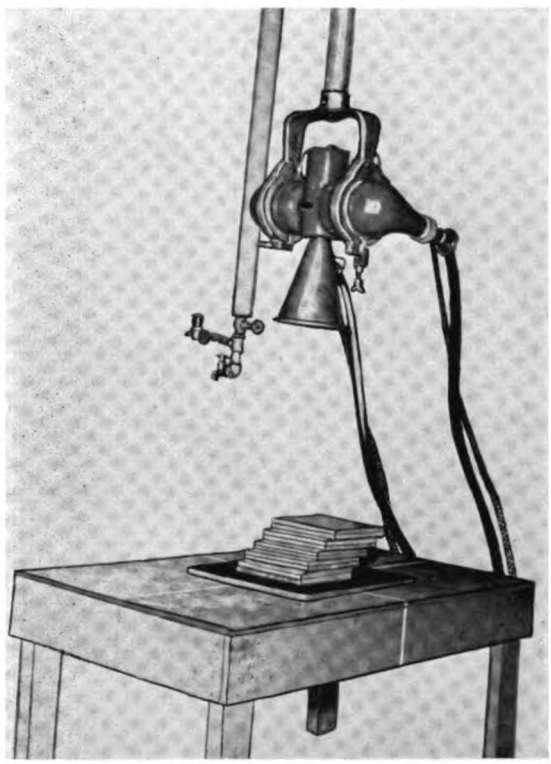


FIGURE 94. Setup for 150 KV Kelly Koett

Eastman Standard Developer at 68 degrees for five minutes. If 0.9 inch of steel is put between the radium and the film, all other factors remaining as above, then the exposure time must be doubled to produce the same density on the film with the same development. If another 0.9 inch of steel is added to the first, the exposure time must be double the exposure required for the first 0.9 inch to produce the same density. That is, the exposure required with no filter is 30 seconds, the exposure required for 0.9 inch of steel is double this or one minute, the exposure required for 1.8 inches is double one minute or two minutes.

The exposure in minutes required without filter, at a 36-inch radium film distance is equal to E (2^n)—in which E is equal to the time necessary to obtain a film density of 1.0, at a 36-inch radium film distance, with the particular film and screen combination used and n is equal to the total number of half-value layers through the section being radiographed.

For any other radium film distance the exposure time varies with the square of the distance.

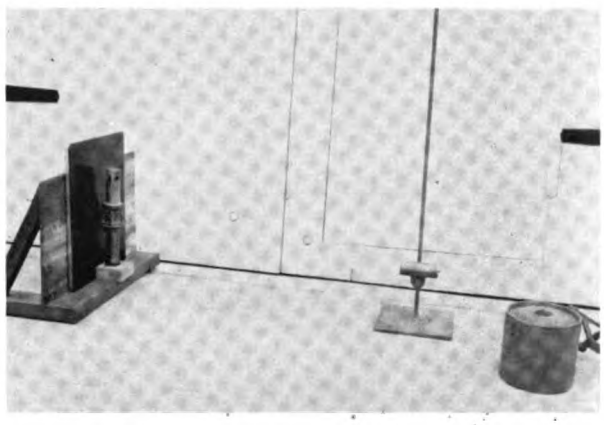


FIGURE 95

Following is a table of half-value layer thickness of different materials ordinarily encountered in the field:

TABLE XII

Material	*Half-value layer thickness*
Lead	0.6 in.
Brass	0.7 in.
Steel	0.9 in.
Aluminum	2.5 in.
Explosives	5 in. to 5.5 in.
Water	6 in.

Following is a table of exposure times necessary, at 36 inch radium film distance, with different film and screen combinations, to obtain a film density of 1.0:

TABLE XIII

Film	*Screens*	*Exposure time*
F	#245	30 seconds
K	Pb	10 minutes
F	Pb	15 minutes
A	Pb	45 minutes
M	Pb	180 minutes

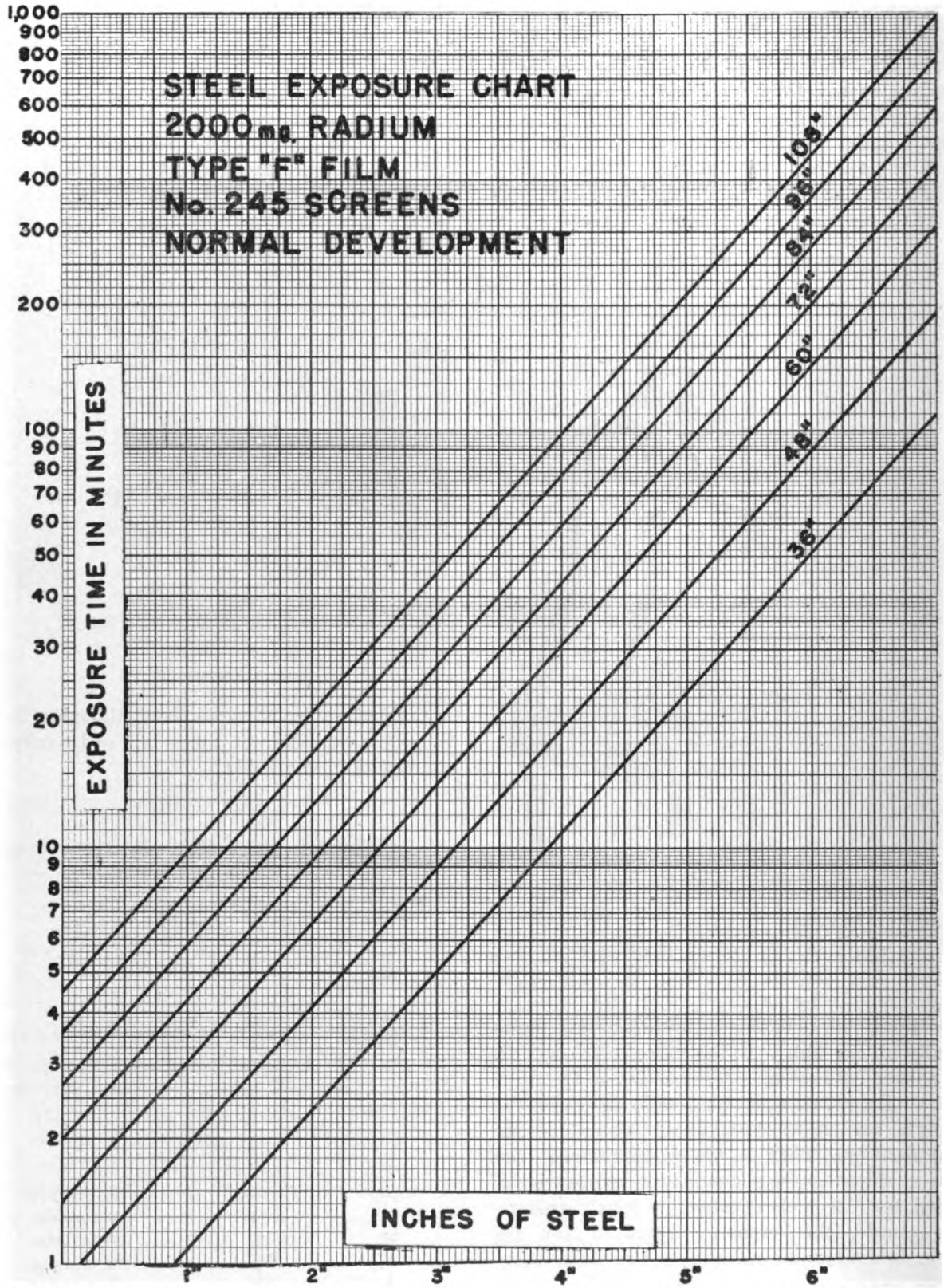


FIGURE 96. Steel Exposure Chart. 2000 mg. Radium Type "F" Film, #245 Screens Normal Development

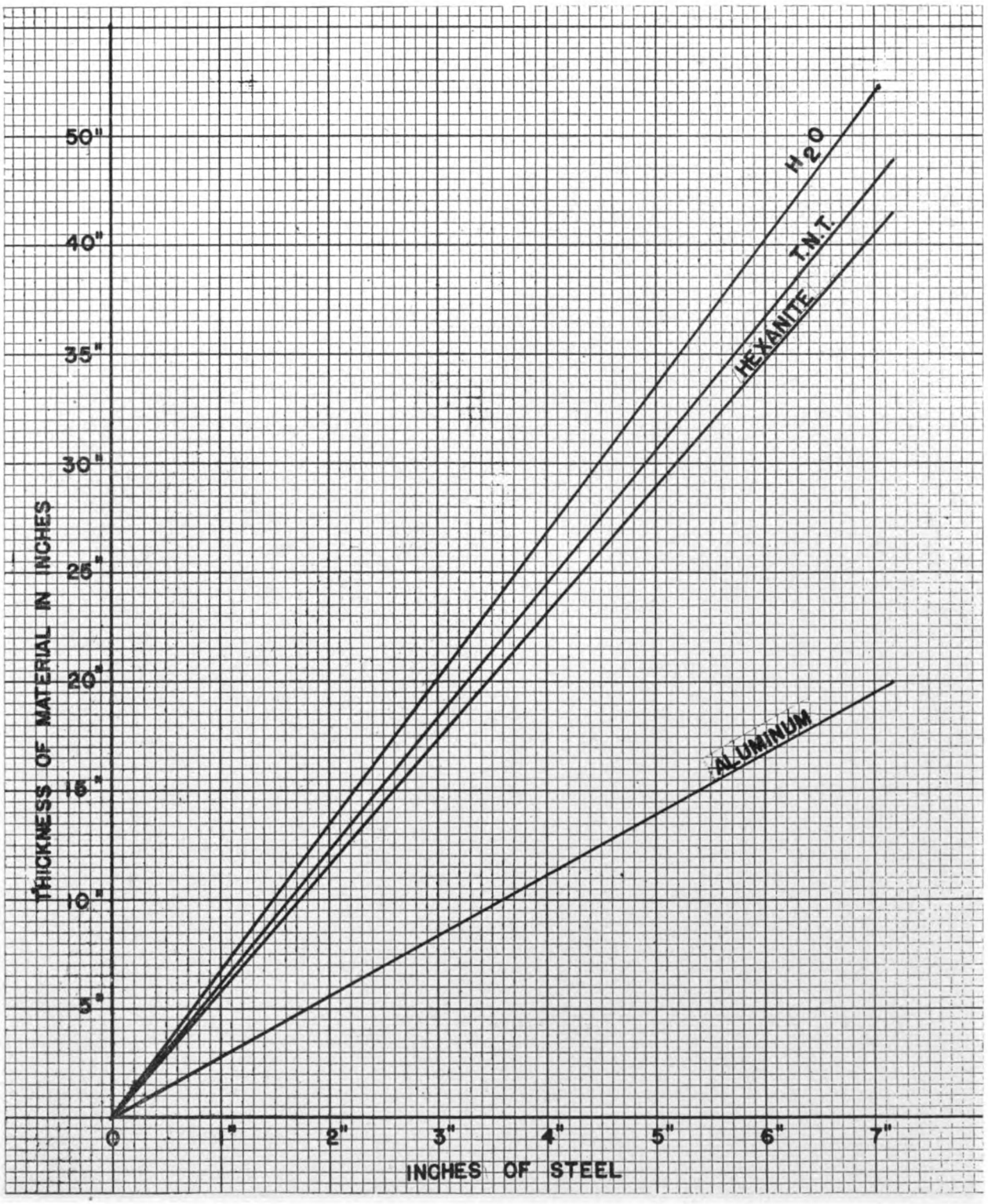


FIGURE 97. Steel conversion chart for use with radium

699810—46—6

FIGURE 98. Radiograph made underwater with no cone and no lead filter

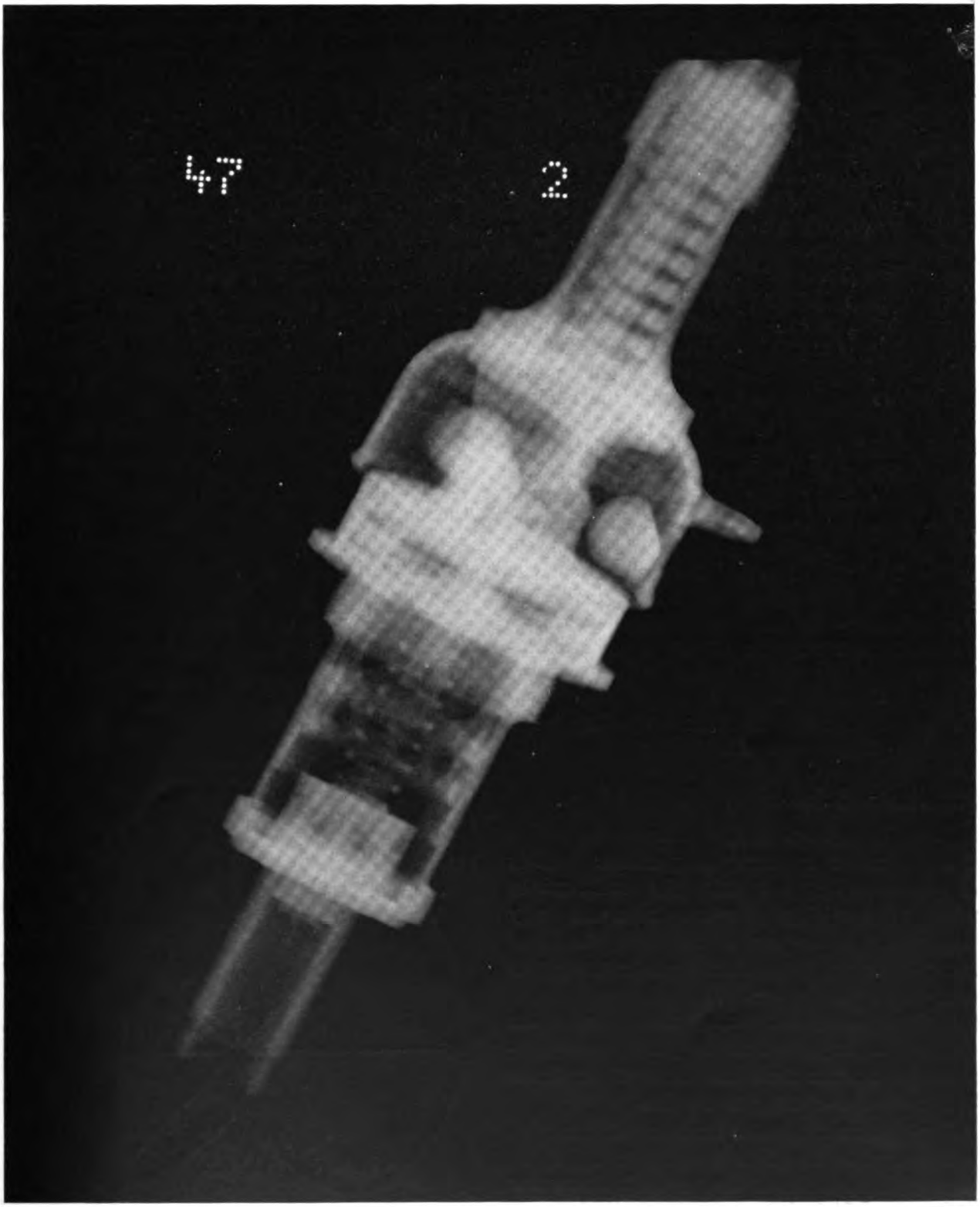


FIGURE 99. Radiograph made underwater with cone and filter

Underwater Gammagraphy

A radium source may be used for radiographing objects underwater. At the Navy laboratory it has been found that the usual radiograph set-up is not satisfactory for underwater work because of the absorption and scatter in the water between the source and film. A weighted, airtight cone was made which has an inbuilt pocket at the apex to receive the radium cylinder. The cone is large enough at the base to cover a 14" x 17" film. In making the actual set-up the film and cassette are placed in a water-proof rubber bag which is secured on one side of the object. The cone is butted against the object on the other side and the radium placed in its pocket. The cone is 36 inches long so the film-to-source distance is longer than this by the thickness of the object. It has been found that there is some scatter from the sides of the cone when it is used and for best results a ⅛ inch lead sheet should be placed in front of the cassette. In case no cone is available a radiograph can still be made but the absorption of the water will have to be added to the absorption of the object in calculating the exposure. It will also be necessary to use a ⅛ inch lead sheet in front of the cassette, to absorb the large amount of scattered radiation from the water.

Filtration and Scattering

It has been found that scatter is quite objectionable when radiographing denser objects and is especially bad under the conditions in which the portable radium unit is ordinarily employed. The exposures are usually made of heavy objects which quite frequently are in pits or lying on the ground. In both cases there is considerable scatter from the ground and in the case of the exposure in the pit there is considerable scatter from the sides which tends to cause under-cutting on the film.

For best results under these conditions, a ⅛ inch lead plate should be placed immediately in back of the cassette to absorb the back scatter and another ⅛ inch lead sheet directly in front of the cassette to absorb the scatter from the object and that scatter from the ground or sides of the pit which tends to undercut the object. These ⅛ inch lead filters may be combined by making a box of ⅛ inch sheet lead leaving one side open to slide the cassette in. When using the ⅛ inch sheet in front of the film the exposure time will have to be doubled in order to obtain the proper density on the film. The reason for this is that the lead absorbs most of the scattered radiation while all of the exposure data was figured with scatter.

In cases where there is a large amount of scattered radiation from the ground or walls of the pit and where the exposure time has to be short as possible, the front lead may be eliminated, if a lead cone is placed around the radium in such a manner as to cut down the field of radiation so that it just covers all of the film. By using the cone the scatter from the object is still present. Consequently the results are not quite as good as those obtained by using the ⅛ inch lead front sheet but the exposure time is halved.

The following is a graph showing the field of radiation from the radium cylinder, and the safe working distances for 4 hours in order to stay within the allowable dose:

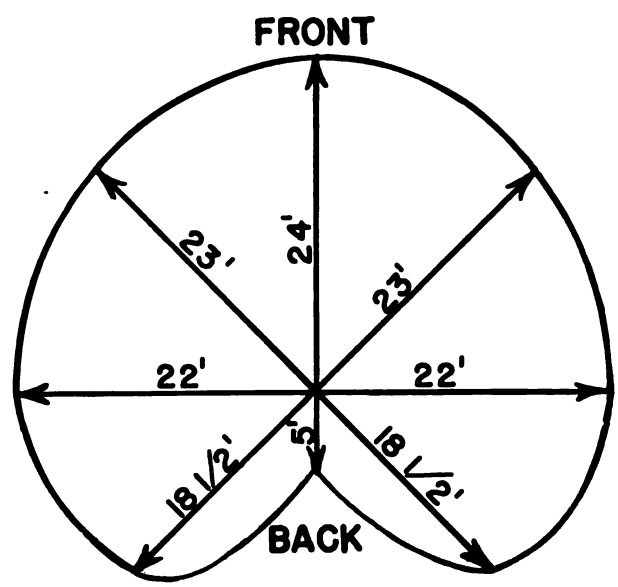


FIGURE 100. Field of radiation from 2 gram radium cylinder front. Distances given are safe working distances in feet for 4 hours

Protection

The allowable or tolerance daily dosage of x-ray or gamma ray is 0.1 roentgen unit per day. This dosage is reached in 3200 millicurie hours with radium at a distance of 15 feet, which would be reached in 1.6 hour with the 2000 milligram source. The allowable dosage at any other distance may be obtained from the inverse square law.

Chapter 11

CHARACTERISTICS OF THE FINISHED RADIOGRAPH

Cleanliness

As much as eight hours' work of two skilled men using expensive equipment can be lost by a moment's carelessness in handling the final product, the exposed film. If it is splashed even by clean water, if it is not thoroughly washed, or if any one of a hundred mishaps occur, it is worthless. It is sometimes believed that once the radiograph is dried it will withstand any treatment. Obviously, this is not so. Moisture in any form, especially on fingers, and dust must be avoided. Films, once dried, should never be out of their preservers for more than a few minutes at a time. In a few hours enough dust may collect on an unprotected film to abrade the emulsion seriously. Films should be grasped by the edges and handled generally as a very expensive and fragile product. Most blemishes can be avoided simply by care and cleanliness.

Density

The information is recorded on the film by varying concentrations of deposited silver measured in terms of density. Densities less than one are relatively non-informative; this is due to the inherent density of the emulsion base, base fog, and to the fact that at the toe of the sensitometric curve, density is not uniformly proportional to the log of the exposure.

Densities above three cannot be easily viewed on ordinary illuminators because they do not provide enough light intensity. Only one thousandth of the light available is transmitted through a film of a density of three. Even with high intensity viewers, not much over a density of four can be seen.

Therefore, in general, a radiograph should possess a density range of one to three. This is not always practical or possible.

Radiographic Contrast and Latitude

In Chapter 4 on film, contrast and latitude are discussed as inherent characteristics of a type film. Radiographic contrast and latitude, however, are a function of these qualities plus kilovoltage, object thickness and absorption, and processing. Since these two film qualities act as reciprocals, they are discussed together.

Developers

Radiographic contrast (and latitude) is affected somewhat by the type of developer used. A sample radiograph of a steel wedge exposed at 400 KV on A film was cut into strips and developed in seven different developers, three common x-ray developers, and four common photographic developers. The development time was that recommended by the manufacturer in each case except that D-72 was developed by inspection. These results are plotted in Figure 101. In order of contrast over the whole range of thickness, the developers are:

TABLE XIV

Developer	Time	Temperature
1. Supermix	5 minutes	68°F.
2. Kodalk	5 minutes	68°F.
3. Standard	7 minutes	68°F.
4. D-72	2½ minutes	68°F.
5. DK-50	8 minutes	68°F.
6. D-76	16 minutes	68°F.
7. DK-20S	5 minutes	68°F.

Over a range of densities between 3.0 and 1.0, the useful range, the order of contrast is changed somewhat. An attempt to assign relative contrasts to the developers is made by dividing the density difference by the thickness difference over this range.

TABLE XV

Developers	Relative Contrast
1. Supermix	33
2. D-72	30
3. Kodalk	28
4. Standard	27
5. D-76	22
6. DK-50	21
7. DK-20S	11

It may be assumed, then, that the latitude obtained from development in DK-20S is three times that obtained from Supermix. DK-20S is the same as DK-20 except that five times as much Kodalk is used.

Processing, Duration of Development

Radiographic contrast (and latitude) is affected considerably by time of development (and/or concentration of developing solutions). The contrast increases with development time up to a saturation point where continued development yields little or no increase in contrast.

In Figure 101 density is plotted against thicknesses of metal plate (.065 in.). One film exposed at 400 KV behind the wedge was cut into strips and each strip developed for a different time in EK Standard at 68°F. The slope of the curves is the measure of contrast. It may be seen that contrast increases with development time up to seven minutes where continued development merely builds up greater overall density.

Object Thickness and Absorption

If two blocks of wood 2 in. x 4 in. x 6 in. are placed side by side and radiographed at about 100 KV through their 4 inch thickness a satisfactory wood grain pattern will be obtained with a medium density range. If one block is turned so that its 6 inch thickness and the other so that its 2 inch thickness must be traversed by the x-ray beam and radiographed again at 100 KV, it will be plain that the density range has increased considerably. The radiographic contrast is much greater. The range of absorption or thickness of object has a great deal to do with the contrast and latitude of the finished radiograph.

Kilovoltage

For general work each film would ideally possess the same radiographic contrast (or a useful density range of 1 to 3).

The most practical way of controlling radiographic contrast is through choice of kilovoltage, given the necessary x-ray generating equipment.

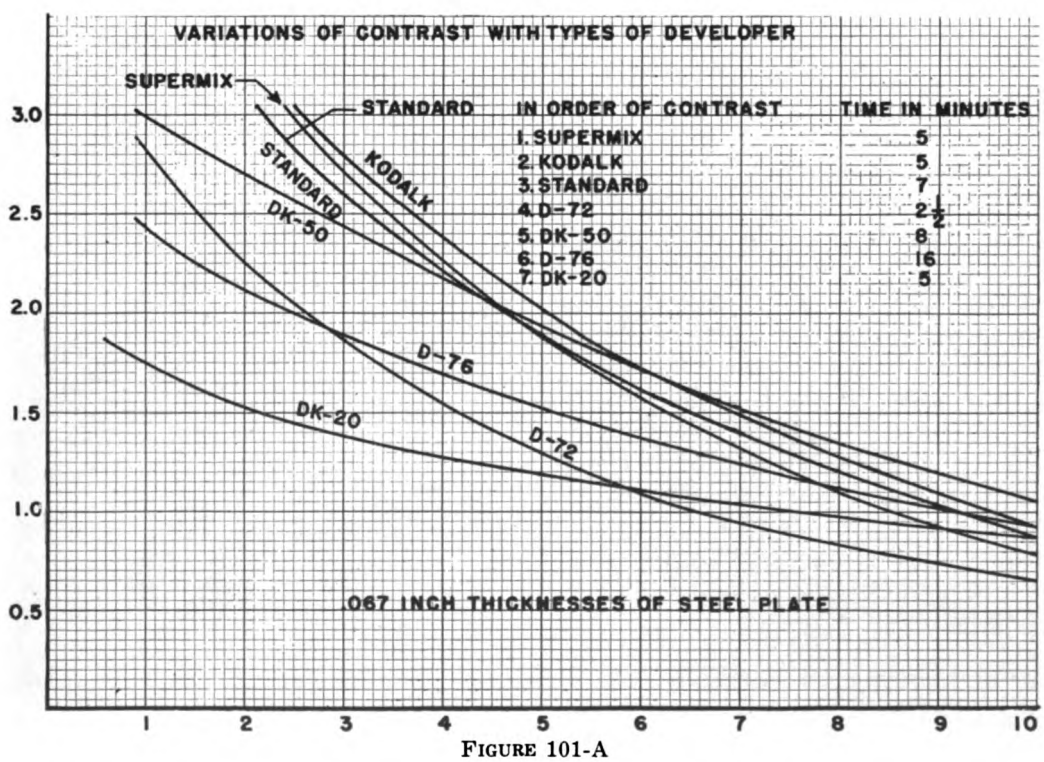


FIGURE 101-A

As voltage increases, the radiation produced becomes more penetrating, and the absorption by the object becomes less; therefore, the film density range is smaller and contrast is reduced. This fact is illustrated fairly well in Figure 102. Four positive prints from original radiographs made with Type F film and calcium tungstate screens are reproduced as a unit to preserve their relative contrasts.

No. 1	150 KV
No. 2	400 KV
No. 3	2 M.E.V.
No. 4	20 M.E.V.

It is plain that for optimum results in routine work neither 150 KV nor 20 M.E.V. would normally be chosen (nor would Type F film and calcium tungstate screens). However, some gradation of contrast is evident, especially between 150 KV and 400 KV.

Definition

By this word is meant simply clarity of detail or sharpness of image line. This characteristic is dependent upon the following factors:

1. *Focal spot size*—The finite spot size produces not only a reduced umbra or sharply defined image but a penumbra or fuzziness which is directly proportional to the size of the focal spot.

2. *Focal film distance*—Definition is directly proportional to this distance for a finite spot.

3. *Object film distance*—Definition is inversely proportional to the distance between the object and film for a finite spot size. The three relationships mentioned above are strictly geometric.

4. *Type of film*—The size of the silver halide grain in the emulsion limits the degree of definition.

5. *Type of screens*—The comparatively large size of the grain in a calcium tungstate screen has a pronounced effect upon definition.

6. *Object thickness or absorption*—Interposing additional absorbers between the film and target whether at the tube or between the object and film decreases definition, roughly in direct proportion. The reason is probably simply due to diffusion or spreading of the beam (i.e., small angular change in the direction of the primary beam due to Compton collision).

In order for an image to exist on the de-

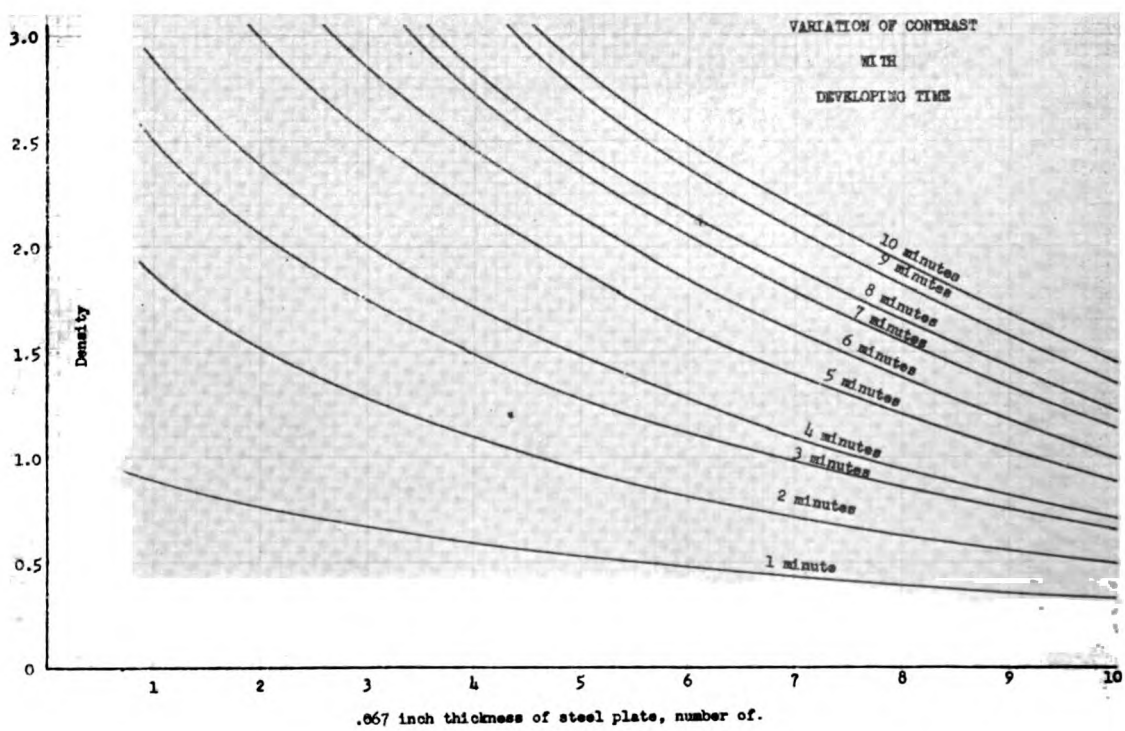


FIGURE 101-B

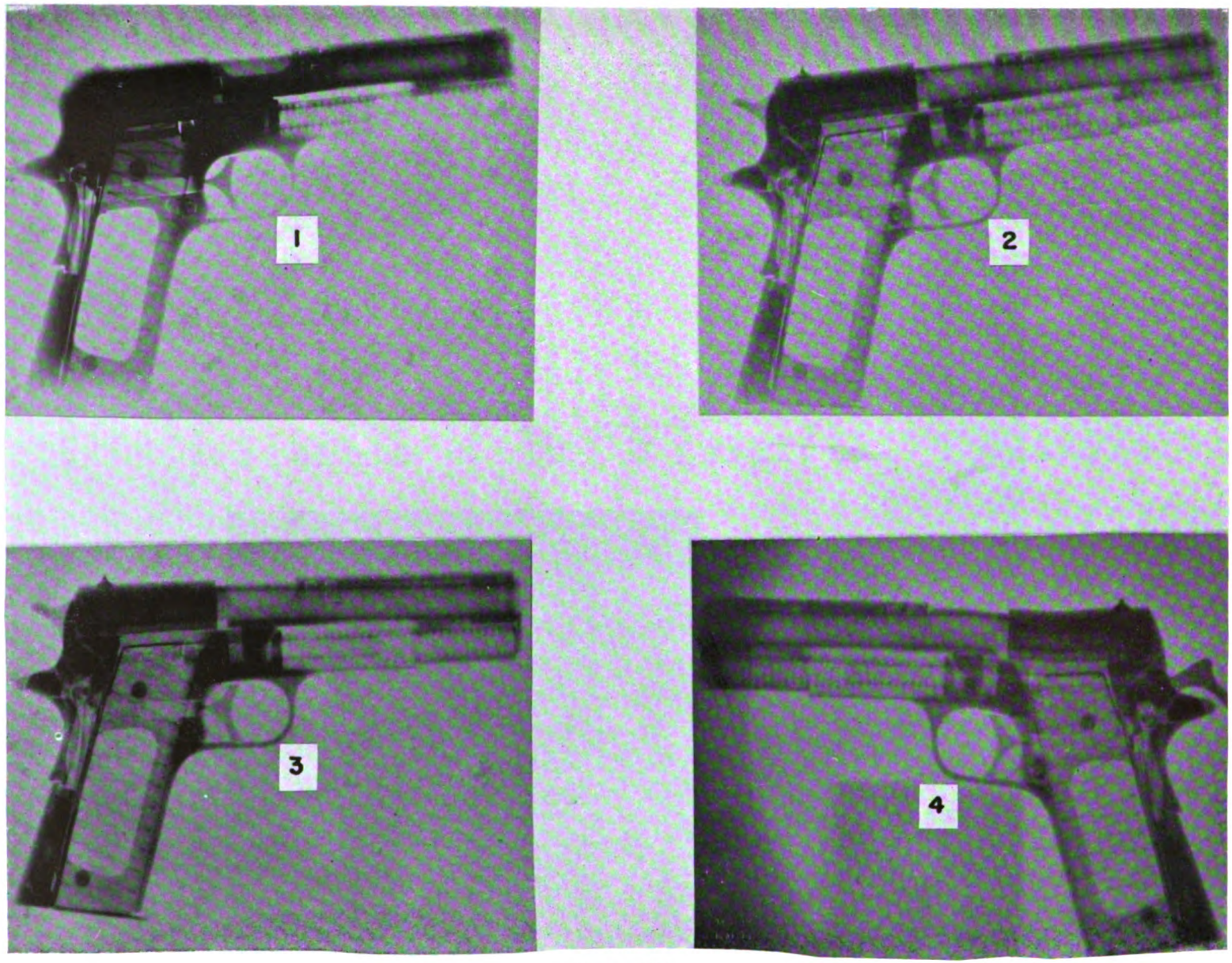


FIGURE 102

veloped film, some contrast or difference in densities must be present; however, the dividing line between a difference in densities of .1 may be just as well defined as between a difference of 1.

Distortion

There are several kinds of distortion of the radiographic image. The commonest are magnification and misalignment. They are due to the geometry of projection.

Magnification

When the object is of considerable thickness, magnification is quite pronounced; it is directly proportional to the ratio of the thickness to the total distance between the film and target. Figure 103 illustrates this in a flange shot of a 21 inch cylinder radiographed at 5 feet. The studs farther from the film appear larger.

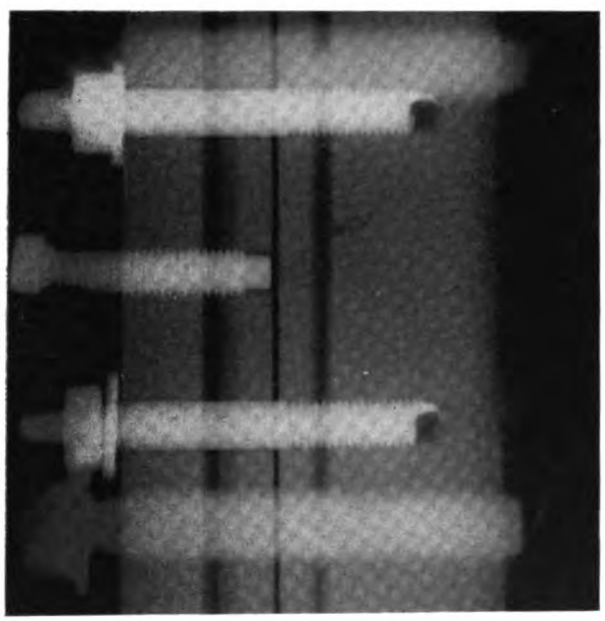


FIGURE 103

Misalignment

There are two cases of this fault; misalignment of the axes of the object with the beam is most common. If the object is a mechanical device like a clock the complex overlapping ovals of the works becomes an almost indecipherable pattern. However, shots through the cylindrical axis and at 90 degrees to it are not so confusing. Figure 104 shows a simple cylinder turned so that orientation is lost.

If the film is not perpendicular to the beam, such as would be the case of the outer-most films under a long object if the entire length is radiographed at one exposure, the misalignment would be very pronounced. This second type may easily be avoided by centering each section of the object in the beam in successive exposures.

Focal Film Distance

Since the intensity of radiation diminishes as the square of the distance from the source it is common practice to use short focal film distances. However, long focal film distances greatly improve the quality of the radiograph; the paths of the photons are more nearly parallel, and less magnification and better definition result. Figures 105 and 106 illustrate the differences between two radiographs of the same object but at different distances.

Object Film Distance

In general, the closer the film to the object the better the radiograph, especially in regard to definition. As the object film distances increase, definition becomes poorer and magnification increases; when it equals the target object distance the magnification is 2× and the fuzziness of a line equals the width of the focal spot.

For ordinary x-ray machines this means that no image exists. However, the Van de Graaff generator possesses so fine a focal spot that very spectacular enlargements may be made. Nevertheless, the loss in definition is still large. The illustration of poor definition in Figure 98 is such an enlargement reduced to less than actual size again.

Graininess

There is a distinct difference in graininess between films developed in Standard and in a Kodalk X-ray Developer. However, this difference is not easily reproduced. Kodalk produces a less distinct image.

Calcium tungstate screens have a very large effect on film graininess due, of course, to the size of the tungstate crystals in the screens. See Figure 108.

Effect of Scatter

In Chapter 6 on scattering and filtration, the effects of scattered light on photographic plates are illustrated and the quantity of scatter present through various thicknesses at higher voltages is indicated. At lower voltages these ratios become very large and important. It is sometimes said that there is no scatter from gamma radiation; unfortunately, this is not true. In all cases scatter must be controlled insofar as possible. There are three effects which may be distinguished on the radiograph, forward object-scatter, back scatter and undercutting.

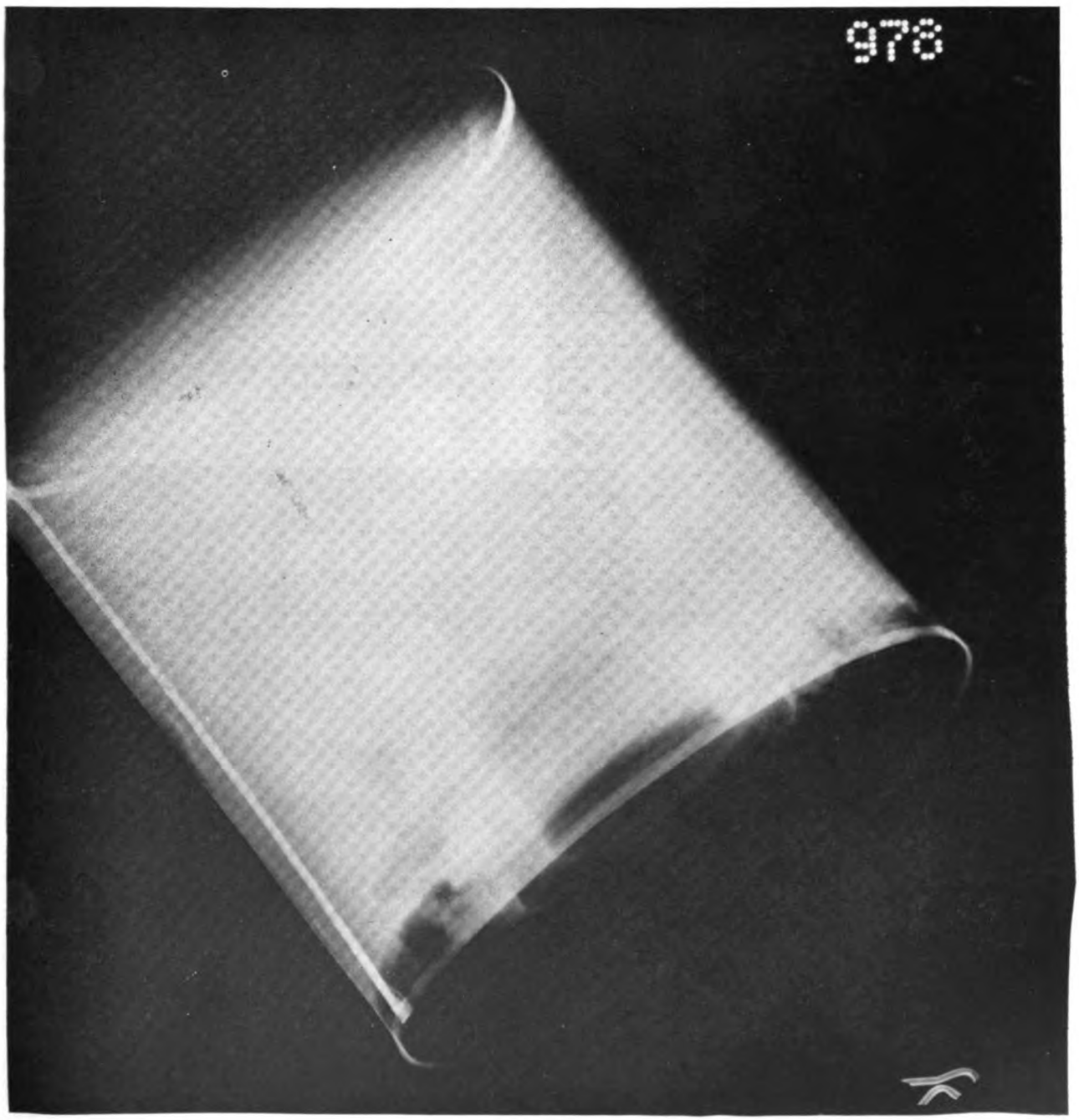


FIGURE 104

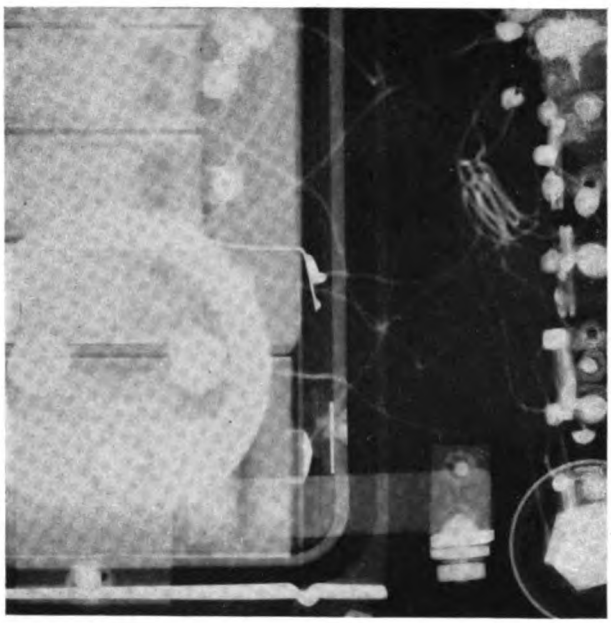


FIGURE 105. Radiograph of combination volt, ohm, milliammeter at a focal-film distance of 12 feet. By using this long focal-film distance the distortion, and unsharpness of line due to focal spot size has been practically eliminated

Forward Object—Scatter

This scatter is most troublesome and most difficult to eliminate. For illustration two films

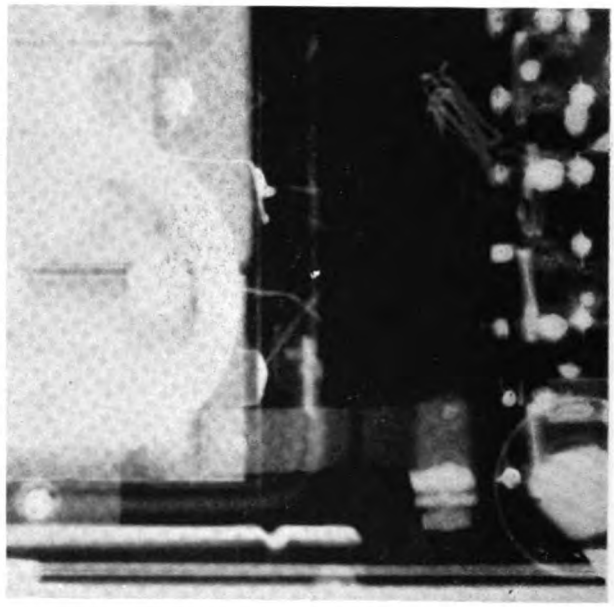


FIGURE 106

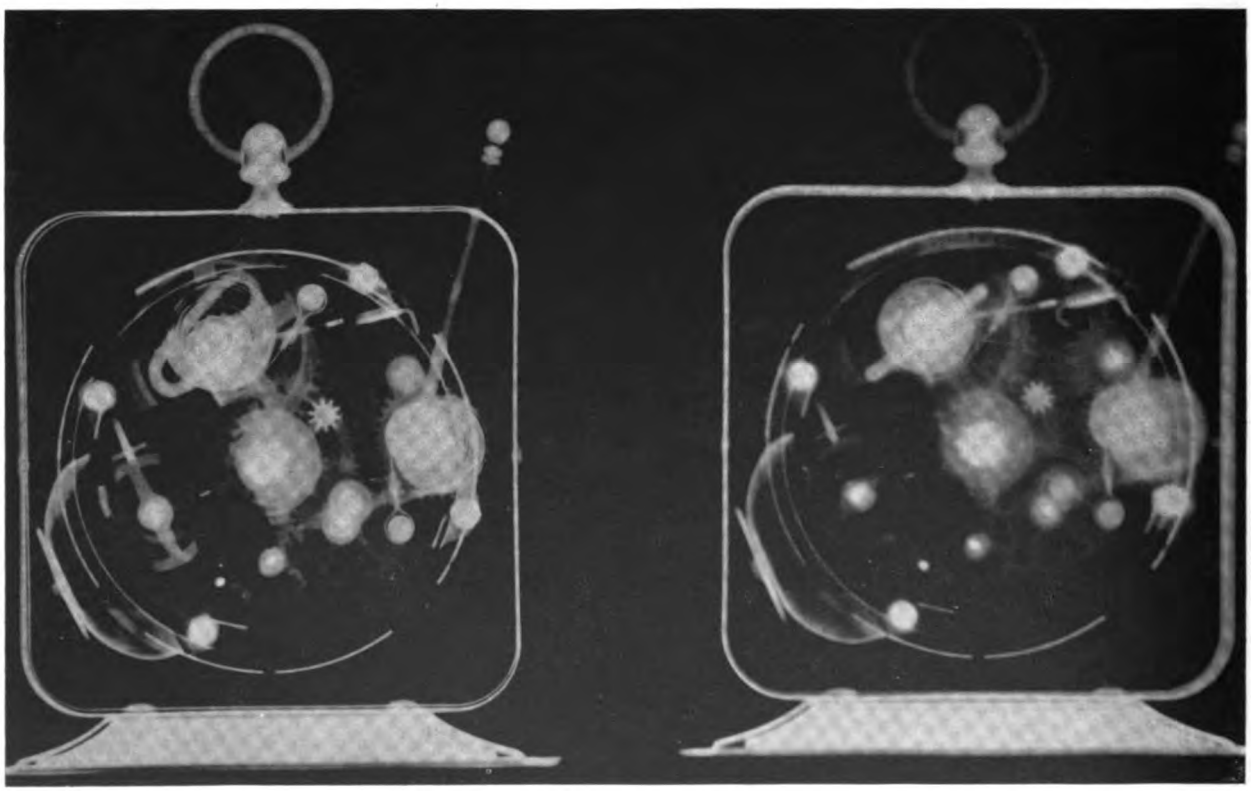


FIGURE 107

are offered for comparison. Both radiographs were exposed to a density of 1.5, using gamma rays.

Back Scatter

Since scatter is radiated in all directions; if the beam strikes a barrier behind the film, it will scatter back through the cassette and fog the film.

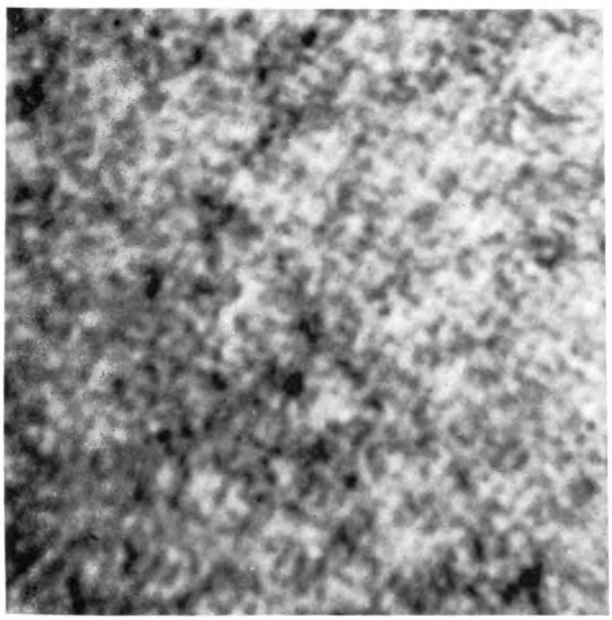


FIGURE 108. The figure above is an enlargement 125 x of a piece of Type F film exposed with Patterson F245 screens. The uneven areas of darkening are characteristic of the calcium tungstate screen

FIGURE 109. Shows the object and the cassette in place. Lead sheet is used behind the cassette only. Figure 110 shows that the image has been practically obscured by forward scatter

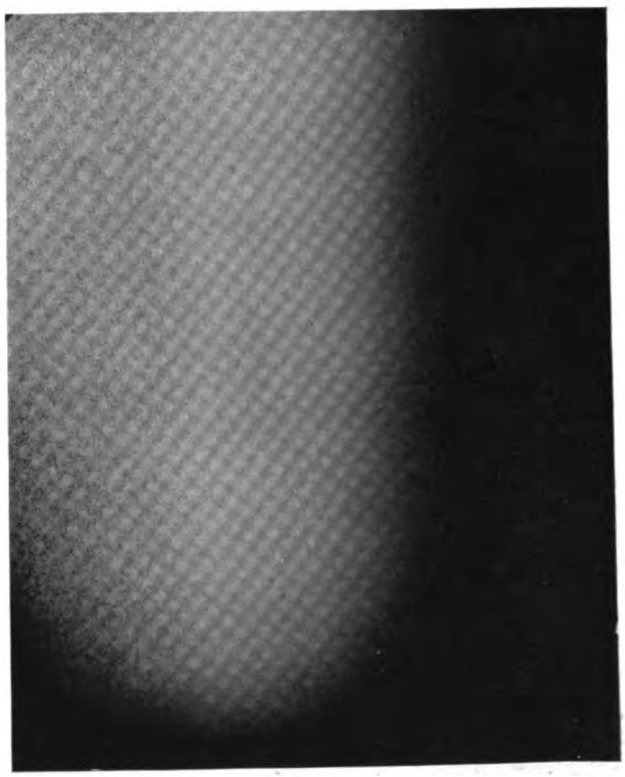


FIGURE 110

FIGURE 111. Shows the same setup again except the back lead has been removed. The result, Figure 112 shows no image but a silhouette of the cassette back straps caused by back scatter

Undercutting

A very common and troublesome form of forward scatter is called undercutting. It is especially noticeable in the radiography of cylindrical objects. The scatter generated at the tangent of the cylinder to the x-ray beam is very intense and often completely obscures the sides of the object image. This type of scatter is illustrated in Figure 115. Examine the hori-

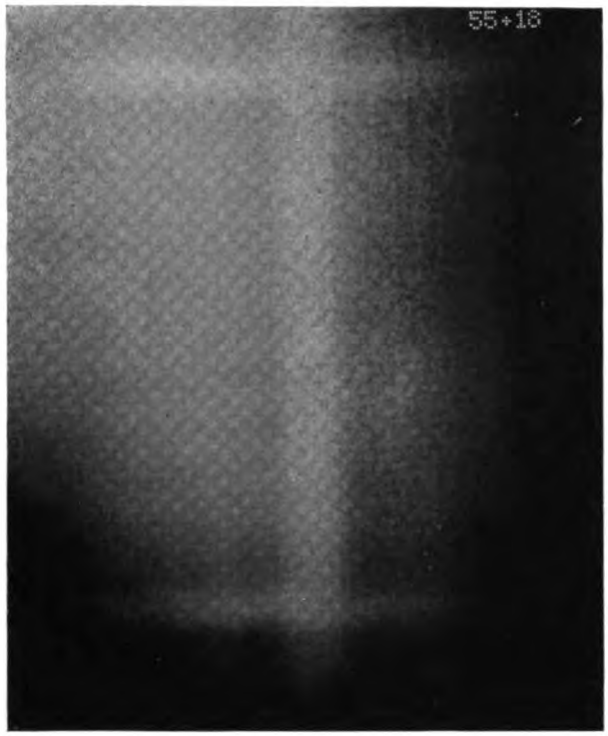


FIGURE 112

FIGURE 113. Shows the same setup except that a second piece of lead has been added to absorb most of the less penetrating object scatter. The result is illustrated by Figure 114

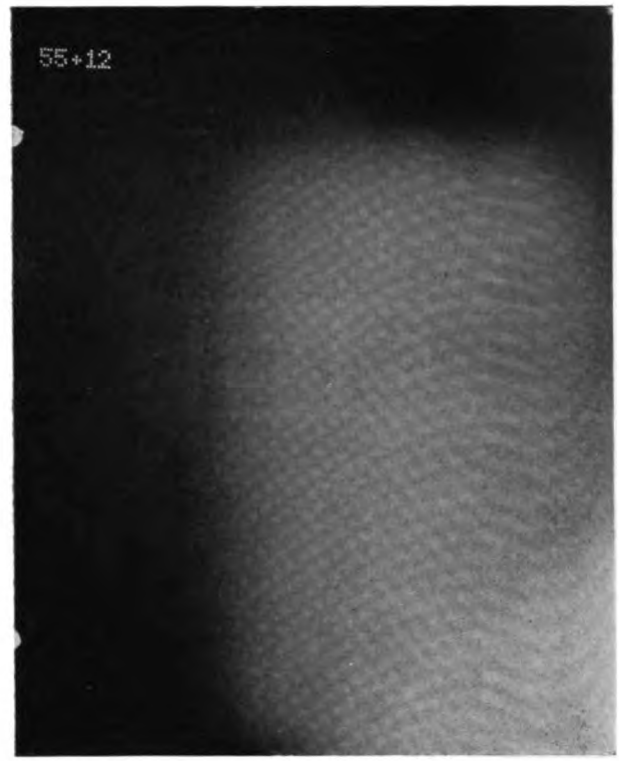


FIGURE 114

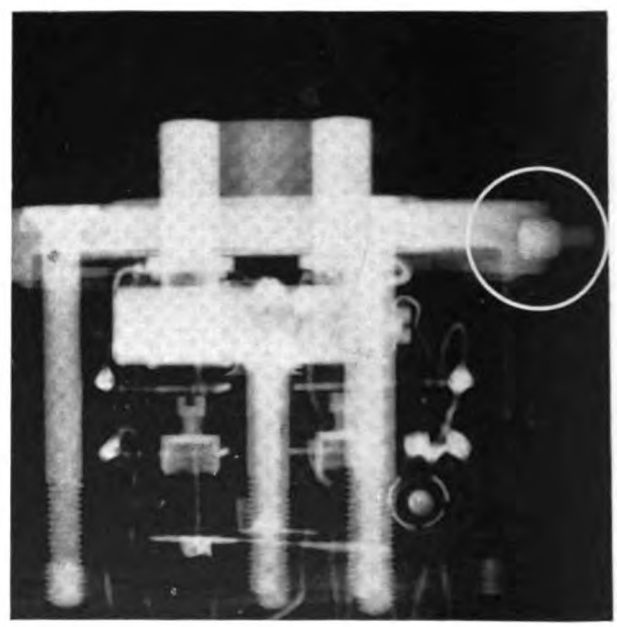


FIGURE 115

zontal locating pin projecting from the upper right side. This is a steel pin set in the aluminum case. The pin is of 2 apparent thicknesses, the outer part is undercut; the inner part is the true diameter, its scatter having been absorbed in the case. The juncture of the outer and inner parts indicates the true outer limit of the fuze flange showing that the amount of undercut on the fuze flange itself is considerable.

This action is greatly assisted by the nature of the emulsion of the film; when a limited area of film is subjected to intense exposure the blackening will "grow" into the unexposed areas.

Chapter 12

VIEWING, STEREOSOCOPY, AND REPRODUCTION

Viewing

Construction of Illuminators—Fluorescent

The common viewer consists of a metal box in which are mounted two 15 watt fluorescent tubes with white reflectors; one side of the box is covered with a sheet of flashed opal glass.

The highest density which may be viewed on this type viewer is 3.0.

The great advantage of this viewer is the small amount of heat generated by the tubes. Films lie flat on the glass and do not buckle with the heat unless the illuminator has been on for a long period.

Incandescent

A less common type employs a 150 to 250 watt mazda lamp behind the flashed opal glass. Using a 200 to 250 lamp this viewer is comparable in light intensity to the two 15 watt tube fluorescent type. The emission of heat and non-uniform area of illumination are disadvantages.

High Intensity Illumination

The General Electric High Intensity Viewer is exactly the same as the common fluorescent viewer except that instead of two there are eleven fluorescent tubes. It is an excellent viewer but extends visibility only up to a density of approximately 4.0.

The Kelly Koett High Intensity Viewer is an incandescent type employing two #1 Photo Flood lamps, a heat absorbing glass filter, two cooling fans and a variac to obtain a range of illumination for viewing densities up to 4.0. It is also provided with a separate 3 inch square high intensity spot incorporating a water filter for viewing small areas of a film.

The Picker High Intensity Illuminator is also the incandescent type; it has a 10 x 10 viewing area, employs a #1 Photo Flood, an infra-red filter, a cooling fan and a variac. It is useful in a density range up to 4.5 but most useful in the low density range to pick up small density differences.

TABLE XVI

OUTPUT

Type of Illuminator	*Relative Intensity*	*Maximum Density*
1. Spot Viewer on KK Hi Intensity	210	5.0
2. Picker Hi Intensity	20 – 72*	4.5
3. KK Hi Intensity, Main Viewing Area	20 – 32*	4.2
4. GE Hi Intensity	22	4.0
5. Large (37 x 52) Viewer	11	3.7
6. Long (17 x 42) Viewer	5	3.4
7. GE Common Viewer	5	3.4
8. KK Common Viewer	4	3.3
9. Wheatstone Viewer	1 – 3½*	3.2

* Incandescent Viewers have non-uniform field of brightness

The amount of illumination in foot candles per 1.1 square inch at the viewing surface may be estimated by multiplying the relative intensity by 50.

One foot candle equals 1 lumen per square foot, equals 1.076 millilamberts; .01 millilamberts should be visible to a normal eye without dark adaptation; however the density difference visible at this low lovel of illumination is only .04. For accurate film reading the light transmitted through the densest area on the film should be at least .1 millilamberts.

Viewing Glass

The function of the glass on the viewer is to diffuse the light so that the field of illumination is uniform. Different grades of glass show different percentages of absorption.

Glass	*Percent Transmission*
Imported Belgian flashed white	80
Replacement GE flashed white	80
Local Commercial flashed white	60
Commercial Ground Glass	90

Ground glass does not provide enough diffusion to give a uniform field.

Color of Viewing Light

The most generally used fluorescent light colors are white and daylight. White is preferable as the film base usually carries a blue tint anyway.

The most restful color for the eye is green. However, its use is not customary even though the efficiency of light production is almost doubled for a green tube.

15 Watt 18 inch Mazda F	*Lumen Output*
White	585
Daylight	510
Blue	315
Green	900

Human Element

It is impossible to view a radiograph satisfactorily in bright light. The light reflected from the surface obscures the image on the radiograph. The eye is accommodated for good vision at the brightness level of the room, not at the low light intensities of 1/100 to 1/10,000 of the viewer output which is the brightness level of the radiograph. Therefore when at all possible the viewing room should be in darkness or semi-darkness.

Direct light, even though partially absorbed by the film, is quite fatiguing to the eyes. When viewing continuously for several hours, avoid glare and relax eyes by looking about and changing eye focus. Eye strain from viewing is common.

Measurements

Knowing the target film distance, the object film distance and the object thickness, it is possible to make accurate measurements directly from the film. For approximate measurements the goemetrical corrections may be omitted for they are usually very small.

The outer sides of cylindrical objects frequently burn out so that the outline of the outer diameter cannot be distinguished. When using A and M film particularly this outline may readily and accurately be determined by reflected light.

Stereoscopy

A well made radiograph of a symmetrical object gives the impression of a flat section or plane cut through the center. Occasionally it is useful to see the interrelation of parts in space. An excellent means of depth perception is the stereoscopic viewing of two similar but not identical radiographs of the same object.

The perception of depth in normal vision is possible because two images of the same object are simultaneously received and effectively superimposed by the brain; the images are identical except for the difference in vantage points, the separation between the two eyes. Depth perception is assisted by the eyes' muscular performance—that is, it is normally impossible for the left eye to be focused on one point and the right eye on another point nearer or farther from the observer at the same time.

In making stereoscopic radiographs the same principles are utilized. Two separate radiographs of the same object are made alike in all particulars expect that the effective vantage points (or points of x-ray source) are shifted by a small amount. The entire illusion of depth must be obtained by this device as the degree of sharpness (or quality of being in or out of focus) over the depth of the radiographic image cannot be altered while viewing. Therefore a maximum definition is sought over the entire area of the image.

The illusion of depth is created by viewing in a stereoscope, which is a device consisting of illuminators, lenses and/or mirrors which allow only one radiograph to be seen by each eye. If the films have been properly made, the observer should be able to superimpose the images and obtain an illusion of depth.

In Figure 116, #1 indicates the perception of depth in normal vision from points *A* and *B* representing the eyes; *A* and *B* may also represent the successive positions of the x-ray source for making two separate radiographs to be viewed on a stereoscope. The distance between *A* and *B* is called "tube shift" or "transfer."

If the source of the x-ray is fixed, the same result may be obtained by moving the object between successive exposures a distance *OO'* called "object shift" or "transfer"; this distance is the same as *AB* mentioned above. If no transfer is practical the object may be rotated. Whatever movement is made must be made in one plane only.

The amount of shift depends upon the target

699810—16—7

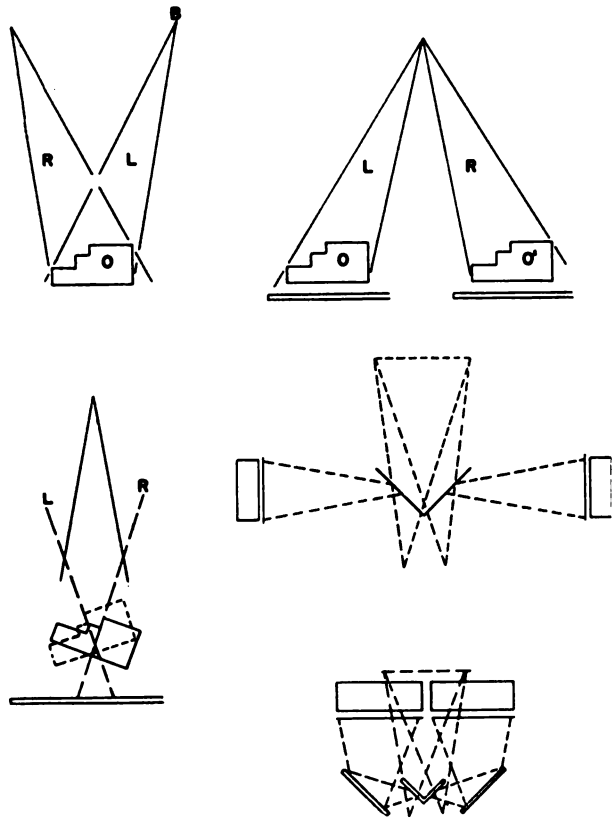


FIGURE 116

film distance, the object thickness, and the maximum image displacement which the eyes can accommodate.

If two stereo-radiographs are placed upon a viewer and the detail on the distant side of the images superimposed, the detail on the near side of the images will lack perfect super-position by a distance called image displacement. It has been determined by trial and error that the maximum image displacement which can be comfortably accommodated by the eyes on 14 in. x 17 in. stereoscopic pairs is 3/8 inch. It has also been found that when the film size (and object size) is reduced, the image displacement must be reduced in direct proportion to the film size.

The accompanying table gives the tube shift for different film sizes, displacements, and object thicknesses at twelve feet. Almost all stereos are made at this distance for optimum definition.

For many objects, especially cylindrical objects, it is well to place the long axis at 30° to 45° to the film in order to exploit the possibilities of depth perception. This effective increase in object thickness must be included in total object thickness in calculating transfer.

TABLE XVII

TUBE SHIFT CHART FOR STEREOS

12-FT. FOCAL FILM DISTANCE

4 x 4 Film Size 1/16" Displacement		6 x 8 Film Size 1/8" Displacement		10 x 12 Film Size 3/16" Displacement		14 x 17 Film Size 3/8" Displacement	
Object Thickness	*Tube Shift*	*Object Thickness*	*Tube Shift*	*Object Thickness*	*Tube Shift*	*Object Thickness*	*Tube Shift*
1/2"	17-1/8"	1/2"	35-7/8"	1"	26-1/8"	4"	13-1/8"
1"	8-1/8"	1"	17-7/8"	2"	13-5/16"	5"	10-7/16"
1-1/2"	5-1/8"	1-1/2"	11-7/8"	3"	8-1/8"	6"	8-5/16"
2"	4-7/16"	2"	8-7/8"	4"	6-9/16"	7"	7-5/16"
2-1/2"	3-9/16"	2-1/2"	7-1/8"	5"	5-3/16"	8"	6-3/8"
3"	2-1/8"	3"	5-7/8"	6"	4-5/16"	9"	5-5/16"
3-1/2"	2-1/2"	3-1/2"	5"	7"	3-1/16"	10"	5"
4"	2-3/16"	4"	4-3/8"	8"	3-3/16"	11"	4-9/16"
4-1/2"	1-1/8"	4-1/2"	3-7/8"	9"	2-1/8"	12"	4-1/8"
5"	1-3/4"	5"	3-1/2"	10"	2-1/2"	13"	3-9/16"
		5-1/2"	3-1/8"	11"	2-1/4"	14"	3-1/2"
		6"	2-7/8"	12"	2-1/16"	15"	3-1/4"
						16"	3"
						17"	2-1/8"
						18"	2-5/8"

In order to preserve the correct orientation, the exposure should be labeled by "left" and "right," and when viewing, the respective eyes must receive these images. When using a Wheatstone viewer with a single mirror, the radiograph must be reversed; that is, the film number and the letters "L" and "R" on the film when viewed in the eye piece should read correctly.

The Fairchild and Ryker stereoscopes are made with front surface mirrors (rhodium coated glass). Great care must be exercised to avoid finger prints and dust. When necessary, dust the surfaces with a camel's hair brush, lens tissue, or clean chamois.

There have been many devices proposed for depth measurement on streoscopes. In general, however, it has been found that 0° and 90° radiographs offer the best method for internal measurements. The great advantage of stereoscopy lies in the fact that the general internal relationships of an object may be studied.

Vectographs

By the Vectograph process, a pair of stereoradiographs may be reproduced reduced in size, and the prints so processed that depth perception is obtained by means of polarized light.

The Kodak Wash-off-relief process is employed to produce the left and right view from the reproduction negatives. Both images are dyed the same color, and mounted on transparent sheets of opposite light polarity. The images are then superimposed but with the right image skewed about ⅛ inch to the right. When viewed through polarized lenses, each eye sees only one image and the effect of depth may be obtained. Vectographs may be made as prints (using an aluminum paint reflector base), transparencies and slides.

Aside from processing difficulties, the chief disadvantage is the short range of density obtainable from the dyed image.

Reproduction

Methods

Very often it becomes necessary to reproduce the radiographic image. If only one or two extra copies are needed, the exposure holders may be "double loaded," that is, two sheets of film inserted with an additional .005 inch lead foil between them, or two holders may be used one beneath or in back of the first. With gamma and 2 M.E.V. radiation there is very little loss of density between the first and last film.

It is also possible to reproduce a radiograph by contact printing it with EK Type F over a fluorescent viewer for about 5 minutes (depending on the original density). The ensuing reversal produces a fair copy though with increased contrast and graininess.

Both Agfa Ansco and Eastman Kodak manufacture a film somewhat similar to Type F in that the principle of reversal is used. However, it is pre-exposed to the point of reversal by the manufacturer.

Usually, however, print reproductions are desired. It is often quite satisfactory and even more practical to use the radiograph as a photographic negative and print directly from it. This method is fast and gives higher fidelity over short density ranges. These prints are sometimes called positives.

The standard method for obtaining reproductions consists in photographing the radiograph and printing from the intermediate negative.

The major problem in copying radiographs is the faithful reproduction of the density range of the original. This usually means compressing a density range of 2 into a density range of 1, because a double emulsion x-ray film has a far greater density range than photographic film. This control of contrast in reproduction is quite difficult unless the density range of the original is small.

Copying the Radiograph

The radiograph is fastened in the normal viewing position to a high intensity viewer having a uniform field of illumination (12 fluorescent tubes) and masked so that no light is allowed to escape except through the film. A sheet of plate glass is then placed over the film to hold it perfectly flat. Light reflected from the surface of the film is eleminated by extinguishing all other lights in the room.

For this work at the Ordnance Investigation Laboratory an f 9.5 Apochromatic lens with a

focal length of 16½ inches is used wide open. The movement of the camera and bellows is standard.

Most reproductions are made on 8 x 10 film. The following films have been used with some success:

1. Eastman Kodak Commercial Ortho—for flat films.
2. Eastman Kodak Super Speed Ortho Portrait—for contrast films.
3. Agfa Ansco Commercial Ortho—for flat films.
4. Agfa Ansco Super Sensitive Ortho—for contrast films.

An elon-hydroquinone developer, DK 50 is used full strength; development is by inspection for contrast control from 3 to 12 minutes at 68°F. It is desirable to obtain a maximum density of 1.0 and a gamma of .8. (Radiographic film often attains a maximum density of 4.0 and a gamma of 5).

No stop bath is used; the film is fixed in EK 5A acid fixer and washed 30 minutes before drying.

The exposure time is calculated from the film speed, corrected for fluorescent light (factor of 2 over tungsten) and the reading of the exposure meter held at 1 foot from the lightest portion of the area to be emphasized. For copying this value is further corrected.

$$E = E_1 \times \frac{V^2}{f^2}$$

E = corrected exposure
E_1 = indicated exposure
V = lens to plate distance
f = lens focal length

If some of the denser portions of the radiograph must be brought out, the proportion of dodging (shadowing one part in preference to another with the hand or piece of cardboard) is calculated by making an exposure meter reading over the denser area.

In order to obtain the final reproduction, the intermediate negative is printed on Azo paper using a range of contrast of #0 to #5 at the discretion of the printer. The print is developed until the image is black. If the previous steps have been correct, the image will be of the proper density. Occasionally dodging is necessary here, too. Lens paper may be placed on a glass shelf 4 inches from the negative to absorb part of the light. At the O.I.L., an Eastman Kodak Model 12 contact printer with a 1000 watt source is used; the average printing exposure is 3 seconds.

Prints are developed about 75 seconds by inspection in D-72 diluted 2 to 1. A stop bath of 1½ oz. of 28% acetic acid per 32 oz. of water is used; all the prints of a batch of 10 to 30 are collected here and transferred to a fixing bath F5a, together, where they remain for 20 to 30 minutes. The prints are washed for 1 hour in a mechanically agitated washer and ferrotyped and dried on a Pako automatic drier.

The great problem in reproduction is to compress the great density range of the radiograph to the small density range of the print. Dodging has been mentioned in the description as a method, but it is uncertain, inaccurate, and tedious.

A very satisfactory method has been developed by J. B. White of the Iowa Ordnance Plant. A film positive is printed from an intermediate negative through a screen (a transparent film on which are printed black 1/16" diameter circular dots the relative areas of clear and opaque film being equal) so that a faint image of the dots will just appear through the densest portion. This speckled positive is then placed upon a printing frame, a piece of opal glass placed above it and between the same intermediate negative which is registered on top. Prints are now made normally. The main objection to this process is the additional work of making the mask.

Chapter 13

INTERPRETATION OF THE RADIOGRAPH

The most important single idea to remember when reading films is that darker areas represent less x-ray absorption and lighter areas represent more x-ray absorption, or, the object is thinner where the film is darker. It may seem unnecessary to emphasize a point so obvious. However, when reading films complicated by overlapping parts, it can be a very helpful aid even to an experienced reader.

The first question to be decided after making a radiograph is—does it fulfill its purpose? Several entirely different radiographs of the same object may be made for different purposes.

1. One thickness or density area may be examined for maximum sensitivity to the exclusion of the rest of the object.
2. An overall general assembly view of the object may be desired without regard to sensitivity.
3. Rigid limits of acceptance on contrast and sensitivity may be set up either for a quality control program or for such films as are to be reproduced photographically.

Uses of Radiographs

Some of the common uses to which radiography has been put are:

1. Inspection of a known or unknown item for details of construction, correct assembly, contents, or condition of safety.
2. Inspection of a known item for internal changes due to externally applied changes such as tension, compression, torsion, heat or cold.
3. Inspection of material for internal homogeneity.
4. Thickness determination.

a. By the use of film for recording the differential absorption of x-rays. A standard wedge must be exposed and developed simultaneously for each thickness measurement. A more accurate means of recording transmitted x-ray intensity is the Geiger-Muller Counter.

b. By triangulation. A pair of stereoscopic films or a single double exposed film, with a tube shift between exposures may be made, employing front and back markers on the object. By triangulation knowing the target-film distance, the tube shift and the front marker shift (measured on the film) the object thickness may be found.

Standards

In large scale inspections of any kind, in order to obtain reasonable uniformity, standards of acceptance and rejection must be set up. Each organization employing radiographic inspection sets up its standards in accordance with its needs.

The Bureau of Ordnance will accept only rocket propellant powder which has been radiographically examined under conditions which will produce a sensitivity of 1% or better and found to be flawless. No grains containing fissures or inclusions visible on the ragiograph are acceptable.

The U. S. Army Office of the Chief of Ordnance has authorized the standards summarized on the following page for the x-ray inspection of 240-mm. shells, TNT loaded. Standards are also set up for 75-mm., 105-mm., 155-mm. and 8-inch shells.

The Bureau of Ships has issued a set of standards on welds and another on steel castings. A summary of the standards on castings is included. The best part of these standards is the inclusion in the original, of films made with both radium and x-rays respectively, of each defect condition. As a result the defect class of the sample may be decided rather definitely by visual comparison.

The Army Air Forces has issued a set of standards for structural castings for aircraft. In ariving at standards, the A.A.F. selects by radiography the three poorest samples of a test lot of 100, and if they pass the static load test those radiographs become the standards for all

castings of that design. However, cracks, cold shuts, misruns, and shrinkage voids are automatic cause for rejection notwithstanding static test.

The following definitions are taken from *Army Air Forces Requirements:*

1. *Cracks* are represented by darkened lines of variable width which are dendritic when caused by hot shortness, and are more nearly linear, or straight, and of more constant width when originating from residuel stresses in solid metal.

2. *Cold shuts* are represented by darkened areas of variable length and smooth outline which tend to be elongated and thin. They occur where the streams of molten metal have come together and have failed to weld together, so that the contact surfaces are oxidized. Cold shuts may generally be detected by visual examination.

3. *Misruns* appear as darkened areas of variable dimensions and smooth outlines where the molten metal has failed to fill the section. Misruns can always be seen by visual examination.

4. *Gas porosity* is generally found in aluminum alloy castings and is due to the presence of dissolved hydrogen in the molten metal. It appears as a well distributed peppering of round or irregular dark spots which tend to be elongated or curved in coarse grained castings. The porosity is distributed throughout the casting, the size of the holes varying with the gas content of the metal and the rate of solidification of the section.

TABLE XVIII

TENTATIVE X-RAY STANDARDS FOR PROJECTILES (ARMY)

Section of Cast	*Flat* No	*Flat* Size	*Ovular* No	*Ovular* Size	*Piping* No	*Piping* Size	*Annular Ring* No	*Annular Ring* Size	*Cracks*	*Allowed Combinations*
B Group—75mm, 3", 81mm, 90mm, 105mm, 120mm										
Bottom—3" from base or ⅓ of cast whichever is less.	0		0		0		0		No Provision	Solitary pores if separated by ¾" solid cast.
Middle — from point 3" from base for 6" or middle ⅓ of cast.	1	¾" x ¾" x 1/16"	2	¼" max. diam.	1	1" x ⅛" aver. diam.	0		"	3 if separated by ¾" solid cast.
Top — remainder of cast above 9" or upper ⅓.	1	¾" x ¾" x 1/16"	2	¼" max. diam.	1	1½" x ⅛" aver. diam.	1	3/16" aver. diam. of individual bubbles	"	4 if separated by ¾" solid cast.
C Group—4.5", 6", 155mm										
Bottom — 3½" from base of cast.	0		0		0		0		No Provision	solitary pores if separated by ¾" solid cast.
Middle — from point 3½" from base for 8".	1	1" x 1" x 1/16"	2	¼" max. diam.	1	1½" x ⅛" aver. diam.	0		"	3 if separated by 1" solid cast.
Top — remainder of cast above 11½".	2	1" x 1" x 1/16"	2	½" max. diam.	2	2" x ⅛" aver. diam.	1	3/16" aver. diam. of individual bubbles	"	6 if separated by 1" solid cast.
D Group—8", 240mm										
Bottom—4" from base of cast.	0		0		0		0		No Provision	Solitary pores if separated by ¾" solid cast.
Middle — from point 4" from base for 10".	2	1¼ x 1¼ x 1/16"	2	⅜" aver. diam.	2	2 x ⅛" aver. diam.	0		"	5 if separated by 1¼" solid cast.
Top — remainder of cast above 14".	2	1¼ x 1¼ x 1/16"	3	⅝" max. diam.	2	2-¾" x 3/16" aver. diam.	1	3/16" aver. diam. of individual bubbles	"	7 if separated by 1¼" solid cast.

5. *Microshrinkage* commonly appears in magnesium alloy castings, and ocsasionally in castings of other alloys, as dark feathery streaks, or as massive areas of fairly definite outline.

6. *Blowholes* or gasholes usually appear as well defined spherical or rounded darkened areas. They are caused by trapped air, mold or core gases, or water vapor and are random in occurrence but tend to distribute on the cope side of a casting.

7. *Dross inclusions.* Dross or oxide inclusions appear as small darkened regions of irregular or indistinct outline, varying in intensity. These tend to be random in occurence but may become localized in cope side of a casting.

8. *Sand inclusions* appear as gray spots of uneven granular texture with indistinct outline. They are random in occurrence but tend to concentrate near the bottom side of a casting.

9. *Segregation* of metallic inclusions (whether or not these properly constitute alloying elements) appear as well defined white spots or as mottled areas, regular or irregular in shape.

The definitions below are based on Army Ordnance Standards:

Flat Cavity—disc shaped cavity perpendicular to the long axis of the shell.

Ovular cavity—common small cavity.

Piping—a long ¼ to 1 inch diameter cavity extending downward from the top of the pour along the long axis of the shell.

Annular ring—a ring-shaped cavity with diametral plane perpendicular to the long axis of the shell.

In 1930 the ASME Boiler Code Committee specified that x-ray examination be used to determine the homogeneity of the deposited weld metal in pressure vessels. A large part of industrial radiography has been devoted to weld inspection.

In the standards mentioned, especially welds and castings, a sensitivity of 2% is required and must be shown by the visibility of penetrameters on the film.

TABLE XIX

CLASSIFICATION OF CASTINGS FOR APPLICATION OF RADIOGRAPHIC STANDARDS (BUSHIPS)

Class 1:

- H. P. Valves and Fittings (wall thickness less than 1 inch). Superheater Fittings.
- Boiler Stop Valves.
- Machinery Castings subject to fatigue or impact stresses (wall thickness less than ½ inch).

Class 2:

- H. P. Turbine Casings.
- Steam Chests.
- Turbine Throttle Valves.
- H. P. Valves and Fittings (wall thickness 1 inch or greater).
- L. P. Valves (wall thickness less than 1 inch).
- Machinery Castings (wall ½ inch or greater.

Class 3:

- L. P. Turbine Casings.
- H. P. Turbine Exhaust Casings.
- L. P. End of H. P. Turbine.
- L. P. Valves (wall thickness 1 inch or greater).
- Machinery castings not subjected to steam pressure.

Class 4:

- Hull Castings less than 3 inches in thickness—subjected to high service stresses.
- Machinery castings not subjected to impact stresses or vibration.

Class 5:

- Hull Castings 3 inches or more in thickness and subject to high service stresses.

TABLE XX

RADIOGRAPHIC STANDARDS

(The plates are an integral part of the standards.)

Type of Defect	*Class Plate*	*Class 1*	*Class 2*	*Class 3*	*Class 4*	*Class 5*
	A1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	A2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
Gas and	A3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
blowholes	A4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	A5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	A6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	B1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	B2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
Sands spots	B3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
and inclusions	B4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	B5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	B6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	C1	Borderline	Acceptable	Acceptable	Acceptable	Acceptable
	C2	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
Internal	C3	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
Shrinkage	C4	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	C5	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	C6	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	D1	Unacceptable	Unacceptable	Unacceptable	Borderline*	Acceptable
Hot tears	D2	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline*
	D3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	E1	Unacceptable	Unacceptable	Unacceptable	Borderline*	Acceptable
Cracks	E2	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline*
	E3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
	F1	Unacceptable	Borderline	Acceptable	Acceptable	Acceptable
Unfused	F2	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
chaplets	F3	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
	G1	Unacceptable	Unacceptable	Borderline	Acceptable	Acceptable
Internal	G2	Unacceptable	Unacceptable	Unacceptable	Borderline	Acceptable
chills	G3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Borderline
	G4	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

* Acceptable only when angle between the defect and the direction of the principle stress is not greater than 20°.

Chapter 14

PROTECTION

Radiation

The biological effects of x-rays and gamma rays that make them useful for treatment also make them dangerous to all who work with or near them. Those who are subjected to even small doses over long periods of time may suffer deleterious changes in the body, indicated by measurable changes of the blood, alterations of glandular tissue, loss of hair and damage to the skin. It is difficult to determine accurately the amount of radiation that can be tolerated by the average person. It is found that there are wide variations in susceptibility from person to person. On the basis of experience gained in past years it is generally agreed that about .1 roentgen per day is a safe dose for persons in normal health, if such persons receive no radiation during at least one month each year. The .1 roentgen is over-all radiation, not localized radiation.

Tolerance doses for the parts of the body vary. Prolonged exposure of the entire body or a large portion of the body will result in headaches and general lassitudes while overexposure of some part may result in an x-ray burn which can become cancerous.

Biological Effects of Radiation

Erythema is a reddening of the skin due to congested capillaries; it may be caused by exposure to x-rays in which case the hair falls out and the injured skin scales off. The amount of radiation necessary to cause this effect is called an erythema dose and varies with the intensity of the radiation. The more intense the radiation the more effective it is; however at 150 KV, 600 roentgens is generally considered an erythema dose.

All parts of the body, however, are not equally affected by radiation.

Dangerous doses for the body tissues are approximated:

Leucocytes	240 R
Salivary Glands	250 R
Germinal Cells	168-300 R
Blood-forming Organs	300 R
Endocrines	333 R
Blood Vessels	400 R
Dermal Structures	430 R
Viscera	750 R
Connective Tissue	1200 R

The quality of radiation has a definite effect on the amount of radiation required for erythema.

THRESHOLD ERYTHEMA DOSES

KV	*Roentgens (including back scatter)*
100	270
140	525
200	680
700	800
1,000	1,000

Protection

For protection against scattered radiation at higher voltages compared with direct radiation, less barrier thickness is needed.

A normal count shows about 5,000,000 erythrocytes (red cells) per sq. cm. and from 6,000 to 8,000 leucocytes (white cells) per sq. cm. Wide variation from the normal indicates a pathological condition which may possibly be due to overexposure to radiation but which may also be due to many other more common disturbances. A monthly blood count is recommended for all x-ray technicians.

If a dental x-ray film with a paper clip on it is carried in the pocket for a period of two weeks and then developed, an indication of the amount of radiation received may be obtained. If an image of the paper clip is visible too much radiation has been received.

For protection against radiation the barrier must be inexpensive and easily constructed. Lead is a very good material requiring only small thicknesses to replace several inches of other materials. Concrete is used more often, however because it is less expensive.

TABLE XXI

MINIMUM WAVE LENGTH AND EQUIVALENT VOLTAGES OF X-RAYS SCATTERED AT 90 DEGREES

Excitation Voltage KV	*Min. Wavelength Primary* Å	*Min. Wavelength Secondary* Å	*Eq. Voltage Scattered*
100	.1234	0.1477	84
200	.0617	.0860	144
300	.0412	.0655	189
400	.0309	.0552	222
510	.0243	.0486	255

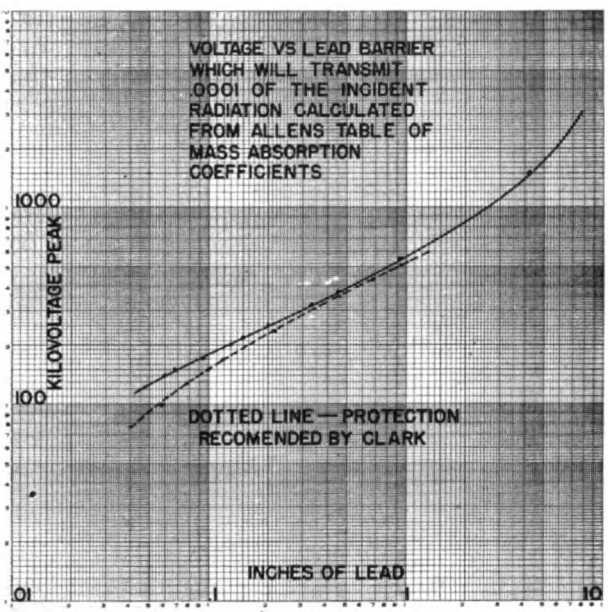


FIGURE 117

Figure 118 shows amount of concrete necessary to provide protection from radiation of 100 KV to 2000 KV. Figure 117 shows equivalent thicknesses of lead over the same range.

The most effective and least expensive protection is distance; for this reason x-ray rooms should be fairly large, at least 250 square feet. For the 2000 KV radiation a lead cone is used to absorb 97% of the angular radiation. This leaves a direct narrow beam striking the deck.

The low voltage exposure rooms have 18 inch concrete walls between rooms and control room. The high voltage exposure room has a 38 inch concrete wall with a maze doorway. All doors have 1/8 inch of lead to absorb radiation that may strike the door. For further information on protection consult National Bureau of Standards Handbook, HB-20.

The high voltage circuits of the x-ray machines present a constant danger to all personnel. Therefore all precautions should be taken when working on the circuits. Deenergize all panels before attempting repairs. When testing circuits be sure no one else is working on the same circuit. Make all connections secure. Consult each chapter for precautions on each individual circuit.

General Safety Rules

1. Handle dry ice with gloves.
2. Use gloves when pouring liquid air or placing flask on tube traps. Rotate thermos bottles when pouring liquid air out of them. Always be prepared for the bottle to burst. Never use near open flame.
3. Use goggles when operating grinders.

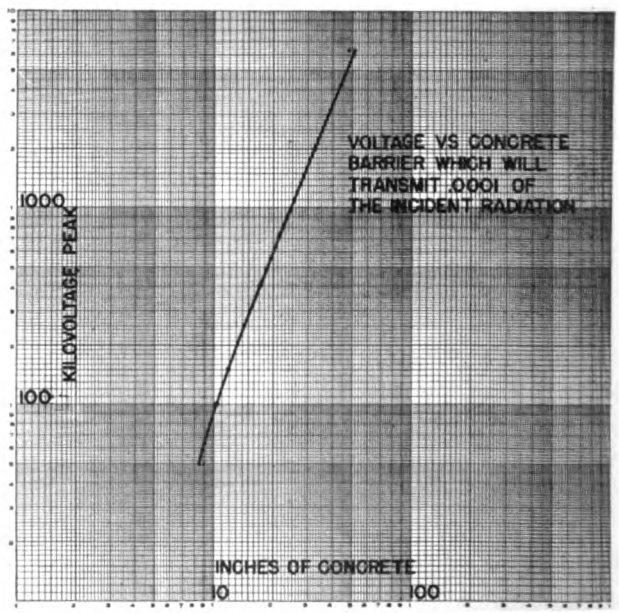


FIGURE 118

4. Keep decks clear of spilled oil and grease.

5. Never allow personnel inside danger areas during exposure. The operator is responsible for all violations of the safety code.

6. Handle ordnance on trucks.
   A. Use chocks to secure objects.
   B. Never raise ordnance higher than necessary.
   C. Travel with ordnance as low as possible.
   D. Travel slowly in the forward directions.
   E. Keep trucks on concrete apron.
   F. Do not bump or jar ordnance.

Explosives

1. Do not smoke when explosive is in target room.

2. Return explosive to magazine as soon as possible.

Chapter 15

MAINTENANCE AND REPAIR OF THE VAN DE GRAAFF GENERATOR

Generator Wiring System

The entire system operates from a 220 volt, 60 cycle, 3 phase power system. The fourth wire is grounded with approximately 110 volts from any phase to ground.

Turning the power on puts the 2 kw variac in the relay cabinet (RC) between one phase and ground. The variac is adjusted to an output of 110 volts and the system is grounded through the power line. The Variac output goes to the main switch in the control panel (CP) on line A1 and the system ground on A2.

Main Switch on Control Panel

Power for the entire system is controlled by the CP main switch except for the vacuum pumps, the battery charger, the compressor and silica gel heater relays, and the cooling protective relays. These are supplied directly from the RC Variac through line A1 and also across other phases. Throwing the main switch does the following:

1. Closes relay 5 which supplies 110 volt power for relays, etc. The output from this relay is sent to RC on A5. From this relay, 110 volts is supplied:

a. To the Selsyn in the Control Panel.

b. To the 110 V Motor on Generating Voltmeter through B14.

c. Through the normally closed contact on the cooling protective relay #2 in relay cabinet to the circulating pump relay which supplies cooling water to the tube target and the magnetic lens. This pump has a 220 volt 3 phase motor.

d. Through the same contact, to the solenoid valve, supplying water to the cooling coil in the pressure tank.

e. Through B14 and the junction box (JB) near the tank, to the Selsyn in tank and the filament transformer for the 6H6 tubes in the generating voltmeter circuit.

2. Supplies 110 volts to magnetic lens switch in control panel.

3. Supplies power for remote operating switch at relay cabinet.

4. Provides power at interlock switch on control room door through K2.

5. Applies 110 volts to relay contacts 4–1, 3–7, 2–6, 2–9, 6–1, and 7–2. (3–7 represents, for example, contact 7 on relay 3.)

6. Applies 110 volts to motor switch on control panel.

Motor Circuit

The motor cannot be started from either CP or RC unless the main switch in RC is thrown for CP operation. Current (110 volt) flows from the motor switch in CP through A8 to RC, through interlock switch to W2 and through pressurestat P2 on tank cooling coil. If there is sufficient pressure on this line to cool tank, P2 closes and if circulating pump relay is closed, the circuit for the motor relay is completed and 220 volts 3 phase is supplied for the drive motor, leaving RC on L1, L2 and L3.

If the interlock switch in RC is thrown for operation from the relay cabinet, as in testing (as is necessary if the tank is open), the motor cannot be operated from CP but only from the motor switch on RC. In this case the relay obtains power from A5 which is controlled by the main switch in CP. Pressurestat P2 and circulating pump relay must also be operating in this case if motor is to run. Extra contacts on the motor relay also controls the input to the high voltage transformer rectifier. The centrifugal switch in the tank also opens this circuit if the main charging belt is not running. These circuits are on B9–B15–B16.

Turning on Voltage

With the main switch on and the motor on, the charge can be applied to the belt.

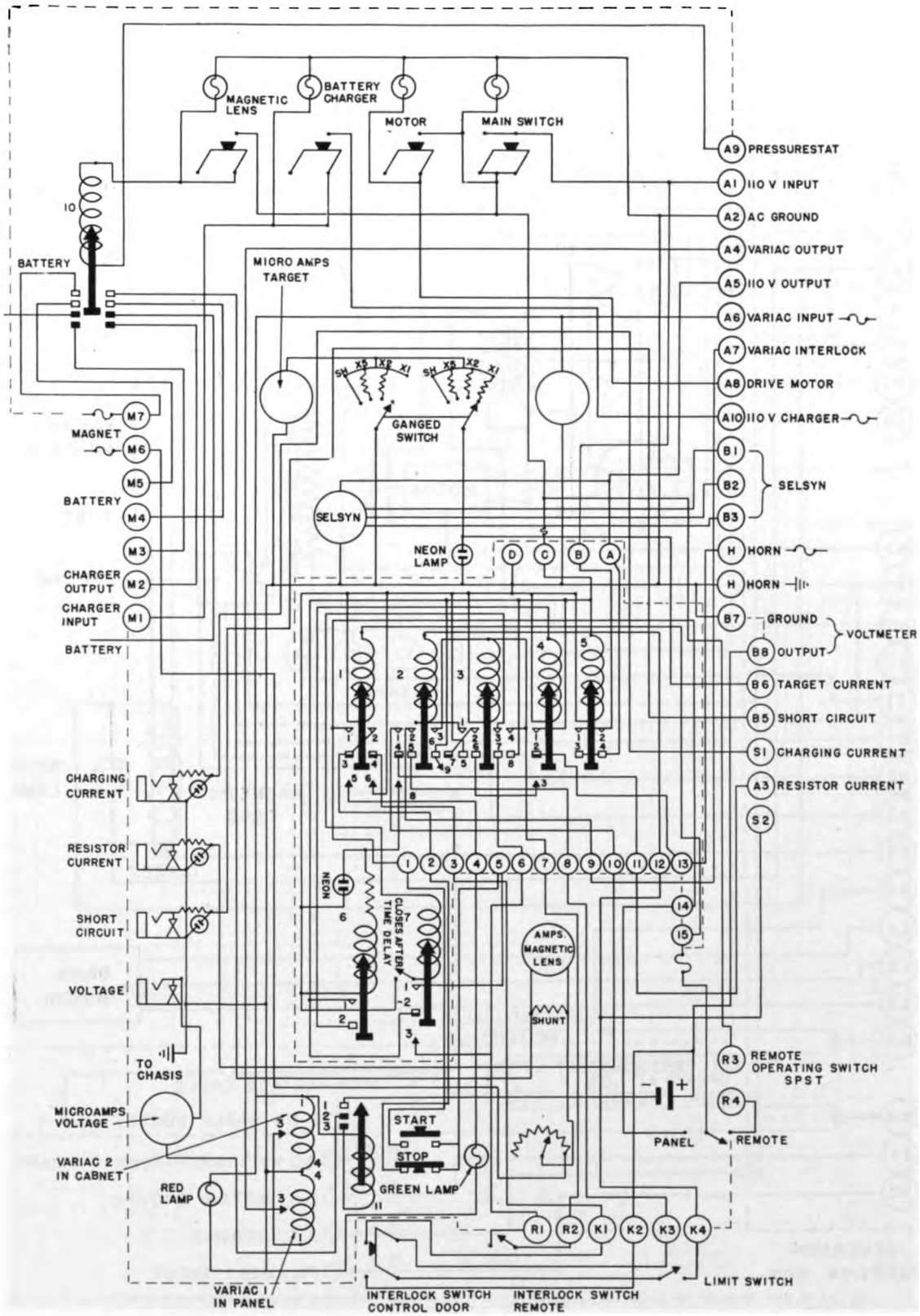

MAGNETIC LENS
BATTERY CHARGER
MOTOR
MAIN SWITCH
A9 PRESSURESTAT
A1 110 V INPUT
A2 AC GROUND
A4 VARIAC OUTPUT
A5 110 V OUTPUT
A6 VARIAC INPUT
A7 VARIAC INTERLOCK
A8 DRIVE MOTOR
A10 110 V CHARGER
B1
B2
B3 SELSYN
H HORN
H HORN
B7 GROUND
B8 OUTPUT VOLTMETER
B6 TARGET CURRENT
B5 SHORT CIRCUIT
S1 CHARGING CURRENT
A3 RESISTOR CURRENT
S2
R3 REMOTE OPERATING SWITCH SPST
R4
REMOTE
PANEL
BATTERY
MICRO AMPS TARGET
GANGED SWITCH
SELSYN
NEON LAMP
MAGNET
BATTERY
CHARGER OUTPUT
CHARGER INPUT
BATTERY
M7
M6
M5
M4
M3
M2
M1
CHARGING CURRENT
RESISTOR CURRENT
SHORT CIRCUIT
VOLTAGE
TO CHASIS
MICROAMPS VOLTAGE
VARIAC 2 IN CABNET
RED LAMP
START
STOP
GREEN LAMP
NEON
CLOSES AFTER TIME DELAY
AMPS MAGNETIC LENS
SHUNT
R1 R2 K1 K2 K3 K4
LIMIT SWITCH
VARIAC 1 IN PANEL
INTERLOCK SWITCH CONTROL DOOR
INTERLOCK SWITCH REMOTE

FIGURE 119

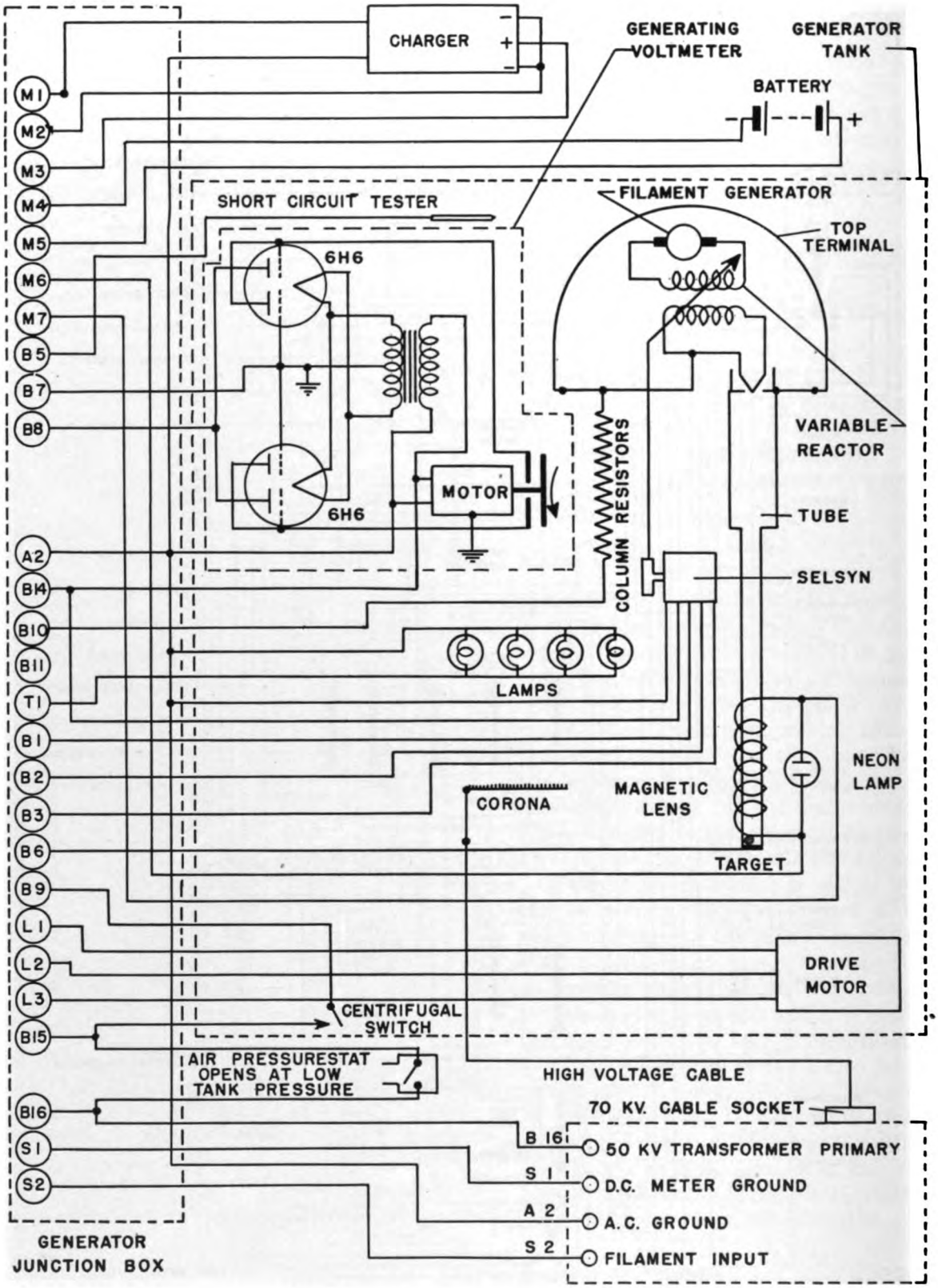
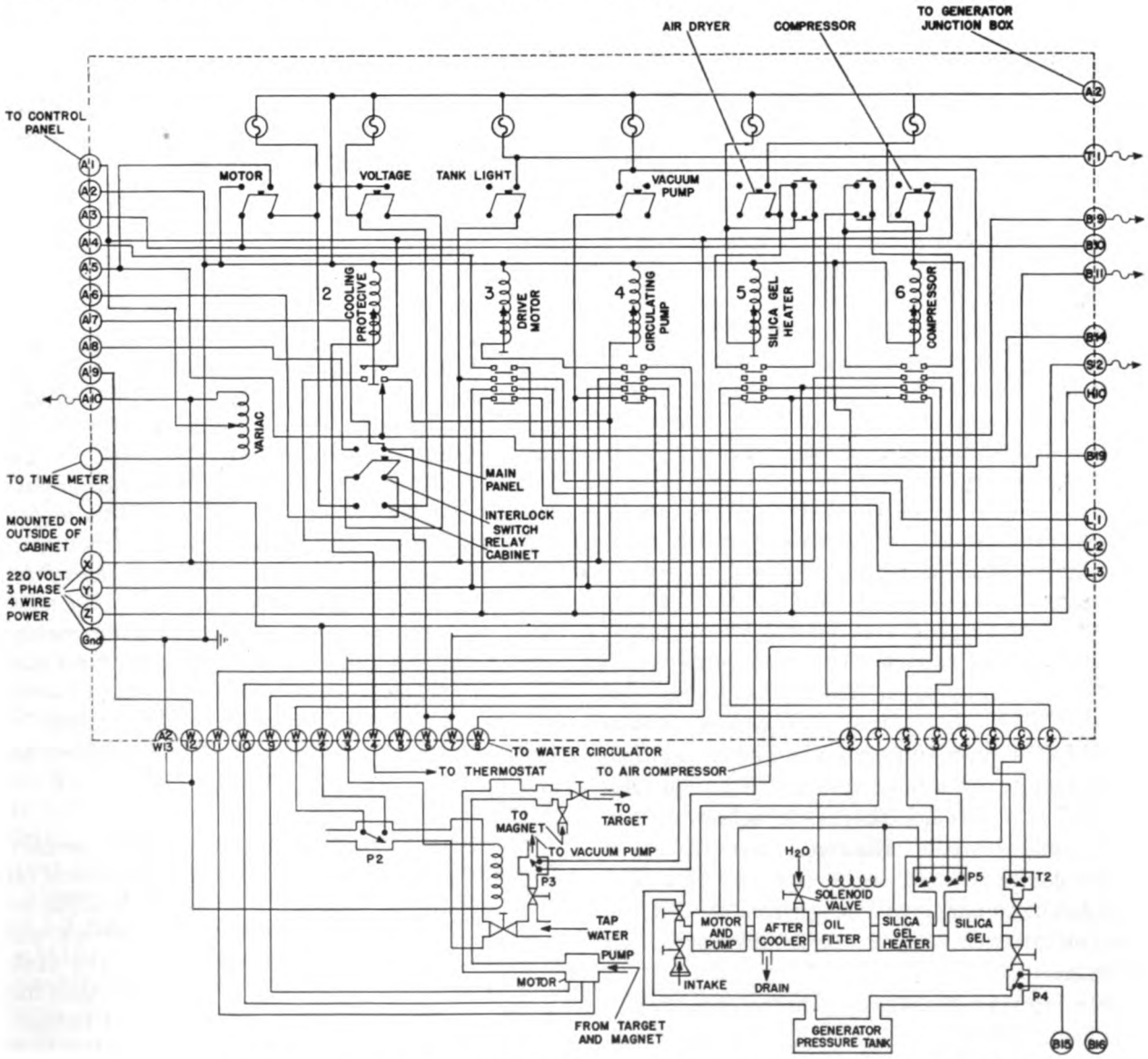

CHARGER
GENERATING VOLTMETER
GENERATOR TANK
BATTERY
M1
M2
M3
M4
M5
M6
M7
B5
B7
B8
SHORT CIRCUIT TESTER
6H6
6H6
MOTOR
FILAMENT GENERATOR
TOP TERMINAL
VARIABLE REACTOR
COLUMN RESISTORS
TUBE
SELSYN
A2
B14
B10
B11
T1
LAMPS
B1
B2
B3
B6
B9
L1
L2
L3
B15
CORONA
MAGNETIC LENS
NEON LAMP
TARGET
DRIVE MOTOR
CENTRIFUGAL SWITCH
AIR PRESSURESTAT OPENS AT LOW TANK PRESSURE
HIGH VOLTAGE CABLE
70 KV. CABLE SOCKET
B16
S1
S2
B 16
50 KV TRANSFORMER PRIMARY
S 1
D.C. METER GROUND
A 2
A.C. GROUND
S 2
FILAMENT INPUT
GENERATOR JUNCTION BOX

FIGURE 120

Turning key A1 in the remote interlock switch closes relay 3 with 110 volts drawn through the normally closed contacts 2 and 3 on the time delay relay 7 (the switch shown in series with the coil of 7 on Figure 119 indicates the time delay action). When 3 closes, the remote interlock switch is shorted out by contacts 4 and 8 of relay 3 (3–4, 8). Opening the remote switch and withdrawing key A1 leaves relay 3 still closed. When relay 3 closes, the coil of the time delay relay 7 is energized through 3–3–7. The action of relay 7 is as follows: contacts 2 and 3 are normally closed and remain so for a predetermined time after the coil is energized (in this case 30 seconds), after which 2 and 3 open and 1 and 2 close and remain closed until the coil is de-energized. When relay 3 closes, the alarm horn in the building is turned on through contacts 2–7,9; 3–2,6; 4–2,3 as a warning to leave the exposure room.



T1 - THERMOSTAT - CLOSES ON TEMPERATURE DROP TO 32°F
T2 - THERMOSTAT - OPENS ON TEMPERATURE RISE TO 212°F
F1 - FLOWMETER - OPENS ON INADEQUATE FLOW
P1 - PRESSURESTAT OPENS ON PRESSURE DROP
P2 - PRESSURESTAT - CLOSES ON PRESSURE RISE TO 50 LBS.
P3 - " " " " " " 40 LBS.
P4 - PRES " OPENS " " DROP " 150 LBS.
P5 - PUMP SAFETYSWITCH - OPENS ON PRESSURE RISE TO 200 LBS.

FIGURE 121

Relay 3 will now be held closed and the horn on, either until 30 seconds has elapsed and relay 7 opens or until key A1 is used to lock the control room door; the switch on topside door must also be closed to complete this circuit. When this is done, 110 volts is applied to the coil of relay 2 through contacts 3–1,5. This must be done within the 30 seconds or relay 3 will have opened and closing the door interlock switch will have no effect. When relay 2 closes, the horn circuit is broken through 2–7,9 and 110 volts is applied to the coil of relay 3 through contacts 2–6,3. Relay 3 is now held closed independently of the time delay relay and will remain closed until either the interlock switch is opened by unlocking the control room or topside doors, or until the main switch is opened. The power input lead A5 to the variac in the CP controlling the high voltage rectifier and hence the charge applied to the belt is now grounded through 1–4,6, the door interlock switch, 2–2,5, and the RC interlock switch.

Since the coil of relay 1 obtains its power through 7–1,2, the machine will be ready to operate only after the time delay has operated. When this happens, a circuit is completed through 7–2,3, the push button and 1–3,5, lighting the green light.

Pressing the exposure start button closes relay 1 which is held closed through 1–1,3. The green light circuit through 1–3,5 is now broken. This circuit is now connected to the 110 volt supply A6 through 1–2,4 and the variac interlock starting the exposure timer, turning on the red light and applying 110 volts to the CP variac. The output from this variac is connected to the high voltage transformer rectifier in the belt spray circuit through lines A4, B9, B15 and B16 through the motor relay and the centrifugal switch. Hence if the variac is turned up, the motor is on and the charging belt running, charge will be sprayed on the belt and voltage will be generated and applied to the tube.

Pressing the exposure stop button breaks the coil circuit of relay 1, opening the relay, turning on the green light through 1–3,5 and grounding the variac input, and turning off the timer and the red light through 1–4,6.

The foregoing is for the case when the toggle switch in the side of the control cabinet is set for panel operating. When set for remote operating, the coil of relay 1 is controlled by means of a SPST switch connected across R3 and R4. The power for the variac and the bias are controlled, as before, by the interlocks and the time delay relay.

For the protection of the target of the x-ray tube, the drive motor relay is in series with P2. The switch remains open unless sufficient water is flowing in the target line to cool the target. Unless the switch is closed, the motor will not run.

When the pressure tank is open, the interlock system holds the RC interlock switch for RC operation. In this position it is not possible to turn on the motor or the high voltage rectifier from the CP. It is possible however to turn on the high voltage from the RC by means of the VOLTAGE switch provided the motor switch in the RC is on. When the voltage switch is thrown A5 feeds S2 directly and lights filaments in the transformer rectifier. With the motor switch on, when the voltage switch is thrown, 110 volts is supplied from the line A5 through the RC interlock switch and line A6 to the CP variac. The variac output as before is interlocked with the motor relay and the centrifugal switch. *Operating with voltage from the relay cabinet should be done only for very special tests and only with someone watching the target current meter. Should the tube become energized a serious and perhaps fatal x-ray burn might result. In addition, the high voltage lead inside the tank is exposed with the tank open and is dangerous.*

Voltage Measurement

The generating voltmeter motor and rectifier filaments are turned on by the main switch on CP. The output from the circuit is brought to CP on lines B7 and B8, both of which are shielded, B7 being grounded both at the tank and to the chassis of CP. B8 goes through the voltmeter microammeter and the bias battery and the sensitive relay to the voltmeter jack on the side of CP and to ground. Relay 6 is shunted and is adjusted so that contacts 6–1,2 close at any predetermined voltage (voltmeter

current), thus closing relay 9 and opening contacts 9–1,2. This is equivalent to pressing the exposure stop button. Relay 8 must be reset manually from inside the CP. Inserting a meter in the voltage jack puts that meter in series with the voltmeter in the panel.

Target Current

The tube target is insulated and the current to it is brought to CP on B6. The ganged switch on the panel serves to change the range of the target microammeter and to protect it from surges by the resistor-neon bulb arrangement. The positive terminal of this meter is grounded through A2.

Charging Current

The current sprayed on the charging belt is measured between ground and one side of the secondary transformer. This portion of the circuit is from ground through the meter jack to one side of the secondary winding through S1.

Short Circuit Current

The no-voltage current output of the generator can be measured by pushing the insulated probe in the side of the tank into contact with the high voltage terminal. This probe is connected with the short circuit jack in the side of CP by line B5.

Resistor Current

The current through the potential dividing resistor in the generator column is brought to the RC on line B10 and to CP on A3. This current is used to actuate a safety device by passing it through contacts 2–4,8 and the sensitive relay 6. Thus, if relay 2 is open (control room door open, or door locked without operating remote interlock switch in proper fashion) and sufficient voltage is generated to give a resistor current of more than 5 microamperes, contacts 6–1,2 close, actuating relay 4. This closes contacts 4–1,2 and turns on alarm horn in building. Should this happen, the horn may be turned off only by the main switch or by resetting relay 6 from inside CP. With relay 2 in closed position (correct operating position) the resistor current goes to ground through contacts 2–1 and the resistor current jack, rather than through relay 6.

When operating from RC, the resistor current is shorted to ground in RC when the motor switch is on. This prevents the horn from blowing when testing the belt for alignment.

Magnetic Lens and Battery Charger

When the main switch in CP is closed, throwing the magnetic lens switch will close relay 10. When 10 closes, the battery bank is connected to the magnetic lens through contacts 10–1,3 and 10–2,4. The current through the lens is adjusted by the variable resistor in CP and by the number of batteries connected in the lens circuit. The current is measured by the ammeter in CP, which should always be used with the proper shunt. With relay 10 in the closed position, it is not possible to connect the charger to the batteries. With the magnetic lens switch in the off position however, the charger output is placed across the batteries through contacts 10–3,5 and 10–4,6 and throwing the battery charger switch to the on position turns on the charger through line M1. The charge current is measured by the meters on the battery charger case. Turning off the main switch in CP does not turn off the charger nor does it disconnect the batteries from it. The batteries may thus be charged overnight while the machine is not in operation.

The following charts show the terminals in each cabinet and box. This will facilitate trouble shooting in showing the position of each lead in the circuit.

Relay Cabinet

The relay cabinet makes it possible to operate the generator from topside and prevents the machine from being operated from the control panel which would be dangerous to personnel when tank is removed.

Switch 1 starts the motor if the interlock is thrown into the correct position, 2 applies voltage to the spray bar, 3 turns on the tank lights, 4 contacts the diffusion pump which is operating at all times. Switch 5 turns on silica gel drier which is started by pressing switch to the right of the cabinet. However the compressor must be operating before the silica gel heater is turned on. The compressor is started by throwing switch 6 and pressing button on the right of relay cabinet.

699810—46—8

TABLE XXII

Control Cabinet

Left		*Right*
O M1 O——Box K	O 38 O——Amplifier	O B6 O——Box D
O M2 O——Box K	O 65 O——CC	O A1 O——RC
O M3 O——Box K	O A6 O——CC	O A2 O——RC
O M4 O——Box K	O A6 O——RC	O A3 O——RC
O M5 O——Box K	O A1 O——RC	O A4 O——RC
O M6 O——Box D	O A1 O——CC	O A5 O——RC
O M7 O——Box D	O A5 O——RC	O A6 O——RC
O A9 O——Box F	O A5 O——CC	O A7 O——RC
O B5 O——Box D	O B1 O——Box D	O R1 O——Reset Box
O S1 O——Box D	O B2 O——Box D	O R2 O——Reset Box
O A8 O——RC	O B3 O——Box D	O K1 O——CR Interlock
O A10O——RC	O H O——Box E	O 38C O——CR Interlock
O A8 O——CC	O A2 O——RC	O C O——CR Interlock
O A10O——CC	O B7 O——RC Box D	O K2 O——CR Interlock
O M1 O——Box K	O B8 O——Box D	O S2 O——RC
O 37 O——Mag. Lens Sw.	O K5 O——Stair Sw. K4 ——Stair Sw.	O K6 O——Stair Sw.

TABLE XXIII

Relay Cabinet

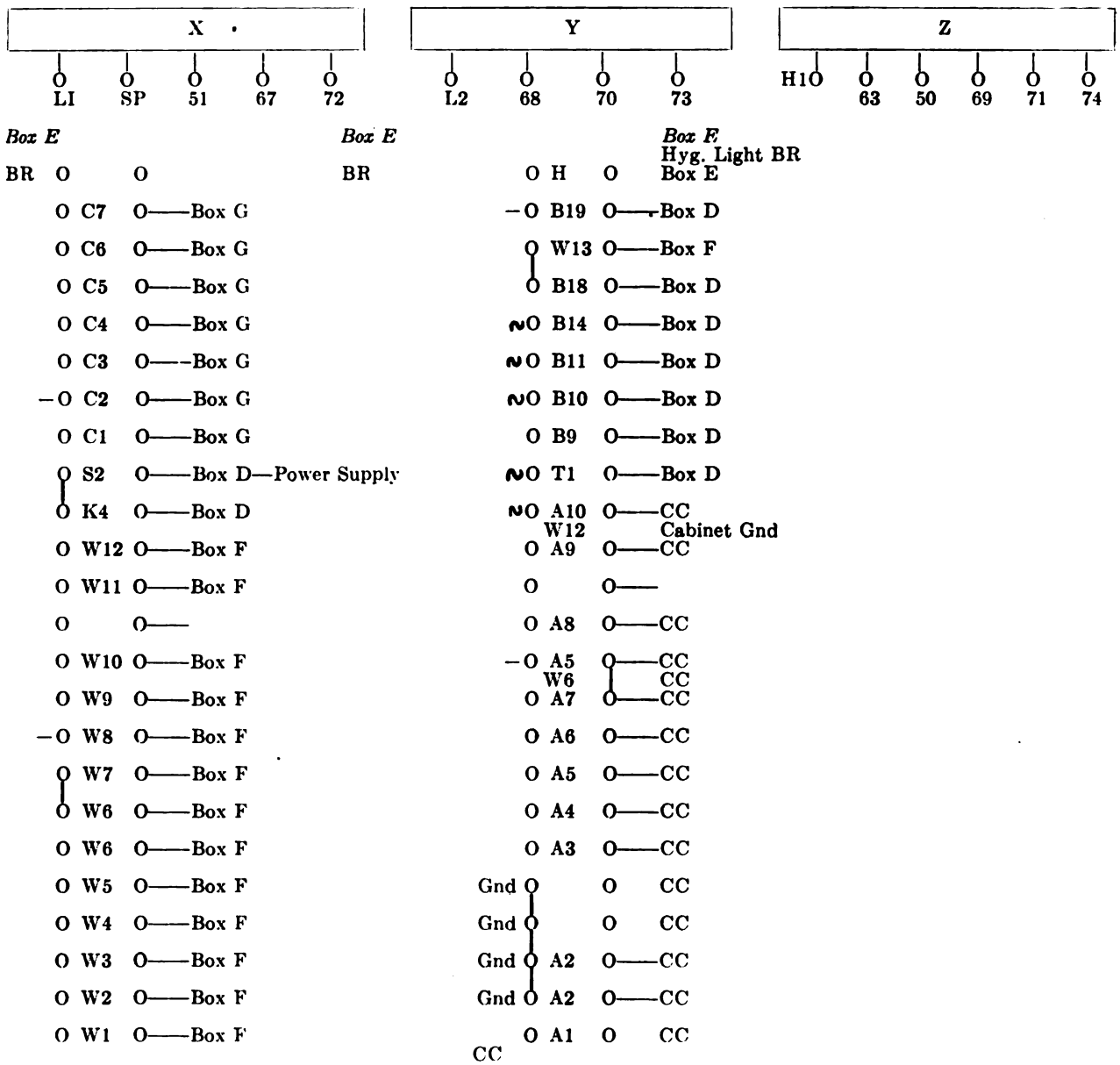


TABLE XXIV

Battery Switch Box

Box K	O A2 O—To Bat. Chg.	Switch	O 50 O—To Batteries
Box K	O M1 O—To Bat. Chg.	Switch	O 21 O—To Batteries
Box K	O M2 O—To Bat. Chg.	Switch	O 22 O—To Batteries
Box K	O M3 O—To Bat. Chg.	Switch	O 23 O—To Batteries
Box K	O M4 O—	Switch	O 24 O—To Batteries
Box K	O M5 O—Switch	Switch	O 25 O—To Batteries
Box K	O M9 O	O 26 O	To Batteries
	O M9 O—Switch	Switch	O 51 O—To Batteries
Box K	O M8 O—Switch	Switch	O 52 O—To Batteries
	O M8 O	O 53 O	To Batteries

TABLE XXV

Box D

CC	O	B10	O	Tank	RC	O	W	O	Power Supply
CC	O	B2	O	Tank	CC	O	S1	O	Power Supply
CC	O	B3	O	Tank	RC	O	S2	O	Power Supply
CC	O	B5	O		Box G	O	B16	O	Power Supply
CC	O	B6	O	Tank		O	E	O	Power Supply
CC	O	B7	O	Box M	RC	O	A1	O	
CC	O	B8	O	Box M	RC	O	T1	O	Tank
RC	O	B9	O	Tank		O		O	
RC	O	B10	O	Tank	CC	O	M6	O	Tank
RC	O	B11	O	Tank	CC	O	M7	O	Tank
RC	O	B12	O		Box K	O	M8	O	Box M
RC	O	B14	O	Box M	Box K	O	M9	O	Box M
	O	B14	O	Tank	RC	O	E	O	
Box G	O	B15	O	Tank		O		O	
	O	B	O		CC	O	M1C	O	Tank
	O		O			O		O	
	O		O		Tank	O	A2	O	
	O		O		Tank	O	A2	O	
	O	E	O		Tank	O	A2	O	
	O	E	O		RC	O	A1	O	Box M
	O	E	O		RC	O	A2	O	Box M
	O	E	O			O	E	O	
RC	O	L2	O	Tank		O	B18	O	Gnd
	O		O			O	B19	O	Box M

TABLE XXVI

Box M (HyVac Protective)

To Center Sw.	—O—E2—O—	DPDT NC Contact Relay Contact
To Center Sw.	—O—E1—O—	Relay Contact
Fuse Wire	—O—E1—O—	Horn (Blk.)
Fuse Wire	—O—M8—O—	Horn (Wht.)
Box D	—O—M8—O—	
Box D	—O—M9—O—	DPDT Sw. (Common Bat.)
To Mcl. Light Box D	—O—A1—O—	DPDT Sw. (Common)
Box D	—O—B19—O—	Trans.
Box D	—O—B8—O—	VM Cable
Box D	—O—B7—O—	VM Cable
Box D	—O—B14—O—	VM
To B8 Shield	—O—A2—O—	VM
Lg. Red Light	—O—A2—O—	McLeod Light
Red Light (wht.)	—O—A2—O—	Box D
To Hyvac	—O—A2—O—	D. P. Htr.
Trans.	—O—B19—O—	D. P. Htr.

TABLE XXVII

Box at Circulator

Box F	O W13 O	Solenoid at Circ.
Box F	O W9 O	
Box F	O W8 O	
Box F	O W7 O	
Box F	O W6 O	
Box F	O W5 O	
Box F	O W4 O	
Box F	O W3 O	Solenoid at Circ.
Box F	O W2 O	Flowmeter F1
Box F	O W1 O	Pressurestat P2
(Black) Pressuretrol P1	O PF O	Flowmeter F1 White
Pressurestat P2	O PP O	Pressurestat P1 White
Box F	O W9 O	Motor
Box F	O W10 O	Motor
Box F	O W11 O	Motor
Box F	O W O	Box Gnd.

TABLE XXVIII

Box F (Circulator)

	O	O	
	O	O	
Circ. Box——	O W13	O——	RC
Circ. Box——	O GND	O——	RC & Box Gnd
Circ. Box——	O W11	O——	RC
Circ. Box——	O W10	O——	RC
Circ. Box——	O W9	O——	RC
Circ. Box——	O W9	O——	RC
Circ. Box——	O W8	O——	RC
Circ. Box——	O W7	O——	RC
Circ. Box——	O W6	O——	RC
Circ. Box——	O W5	O——	RC
Circ. Box——	O W4	O——	RC
Circ. Box——	O W3	O——	RC
Circ. Box——	O W2	O——	RC
Circ. Box——	O W1	O——	RC

TABLE XXIX

Box G (Compressor)

	O	O	
	O	O	
Comp. Box——	O H10	O——	RC (Z)
Comp. Box——	O B16	O——	
Comp. Box——	O B15	O——	
Pressurestat P3——	O B19	O	—Box D
Pressurestat P3——	O B18	O——	RC
	O	O	
			Gnd to Box
Comp. Box——	O W	O	RC
Comp. Box——	O C4	O——	RC
Comp. Box——	O C5	O——	RC
Comp. Box——	O C7	O——	RC
Comp. Box——	O C6	O——	RC
To Motor——	O C3	O——	To RC
To Motor——	O C2	O——	To RC
To Motor——	O C1	O——	To RC

TABLE XXX

Box at Compressor

	O			Gnd Hyg. Light
	O		O	
	O		O	
Box G	O	H10	O	Hygrometer Light
Box G	O	B15	O	To pressuretrol, P4
Box G	O	B16	O	To pressuretrol, P4
	O		O	
Box G	O	C5	O	Temp. Contr.
Box G	O	C4	O	Temp. Contr.
Box G	O	W	O	Solenoid
	O		O	Box Gnd.
	O		O	
Box G	O	C7	O	Silica Gel. Htr.
Box G	O	C6	O	Silica Gel. Htr.
Box G	O	C3	O	To Motor, Press, Sw.
Box G	O	C2	O	To Motor, Press, Sw, Solenoid
Box G	O	C1	O	To Motor

TABLE XXXI

Box E (Beach Russ Wiring)

L1	L2	L3	Horn		Reset interlock		RC	Gnd
O	O	O	O H	O S1	O R2	O S2	O W	

			H	S1	R2	S2	W
O	O	O	O	O	O	O	O
X	Y RC	Z	RC		CC R2	RC W2	Horn Gnd

Water Circulator System

The water circulating system is used essentially to provide cooling for the gold x-ray target. In addition it is used to cool the coil attached to the magnetic lens casing. It consists of a circulator and is turned on with the *main switch* at the control panel. See Figure 123, for a picture of this system and Figure 124,

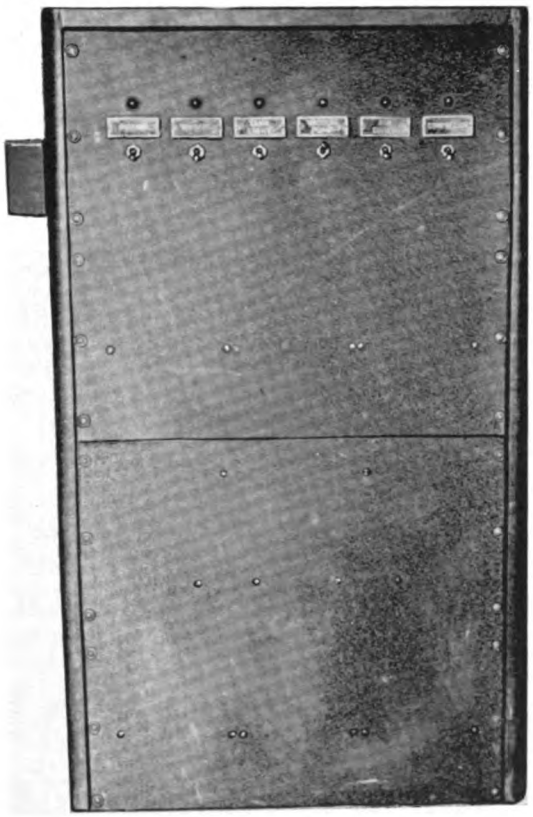


FIGURE 122. Relay cabinet

this section, for a diagram showing the complete water circuit. Refer to Figure 121 for the electrical wiring circuit. The main switch energizes a solenoid water valve permitting water to flow through the tank coil. This water also serves as the heat-exchanging medium for the circulating water. Since the gold-target assembly is insulated electrically from ground to provide a means of measuring the tube current, it is important that the circulating water used for this cooling be free from conducting ingredients. To insure high resistance to ground, distilled water is used and about 25 feet of saran tubing for lengthening the resistance path to ground. Because the circulator unit itself is not entirely free of extraneous matter, the insulation of the target current lead (B6) should be checked periodically, at least once weekly. The water should be changed and the system flushed if the resistance to ground is less than 150 meghohms. The flow switch shown in the diagram is for the purpose of turning off the x-ray beam in case water flow to the target stops. The water level should be half the height of the gauge. When changing the water in the circulator, follow the valve schedule on figure below.

Compressor

Compressed air at 200 lbs./sq. in. pressure is used as the electrical insulating medium in these generators. One essential requirement for satisfactory operation is that this air be absolutely free of any oil and water vapor. To make this air, oil, and moisture free, it is pumped through the compressor after-cooler, a container of silica gel drying agent, and a copper coil cooled to dry ice temperature. When the tank is pumped up, the after-cooler takes out the greatest amount of water and oil, this portion being filtered out in a series filter which empties into a water trap and thence into a drain. Small traces of moisture and oil are further absorbed by the silica gel, and still smaller traces are trapped in copper CO_2 cooled coil. In time, the porous silicon stone in the filter unit may become saturated with oil and water, thereby reducing the efficiency of filtration. For this reason, this unit should be disassembled and cleaned with CCl_4 about once a month. The silica gel can be reactivated for repeated use by passing through it hot air (at 240°F.), thus permitting the evaporation and removal of any moisture absorbed by it. After prolonged use, however, the silica gel grains may become clogged with oil, reducing their ability to absorb moisture; hence they require replacement.

This is done by breaking unions at the ends of the container and removing from the compressor. The Allen bolts are removed, releasing the plate on the end. Care is necessary because of the strong spring beneath the plate. Remove all of the former grains and clean thor-

oughly: replace with silica gel just opened and seal container of silica gel immediately. New silica gel must be dried before using.

Upon the installation of a new charging belt and after the initial vacuum drying period, it will be found that, despite a low dew-point reading on first pumping up to 200 lbs. pressure, after several hours of running the belt, the dew-point of the air in the tank has risen. This is attributed to moisture trapped in the belt lining freed by running the belt. In order to eliminate this additional moisture, then, provision has been made to dry further the tank air by circulating it through the silica gel and the CO_2 cooled coil while the tank remains at 200 lbs. pressure. This is done by re-admitting the tank air into the compressor through a pressure reducing valve (an Airco Oxygen Regulator) and allowing the compressor to pump this same air through the silica gel and cooling coil and back into the tank.

Care should be taken in the adjustment of the Airco Regulator Valve because the compressor inlet valve is not capable of withstanding more than 25–30 lbs. pressure. For smooth operation of the compressor during circulation, the Regulator should be adjusted to about 2–5 lbs., in which case a complete change of air is made in about two hours. This treatment may be necessary for several hours and should be continued until the dew-point temperature drops and *remains* below –50 C. Because the

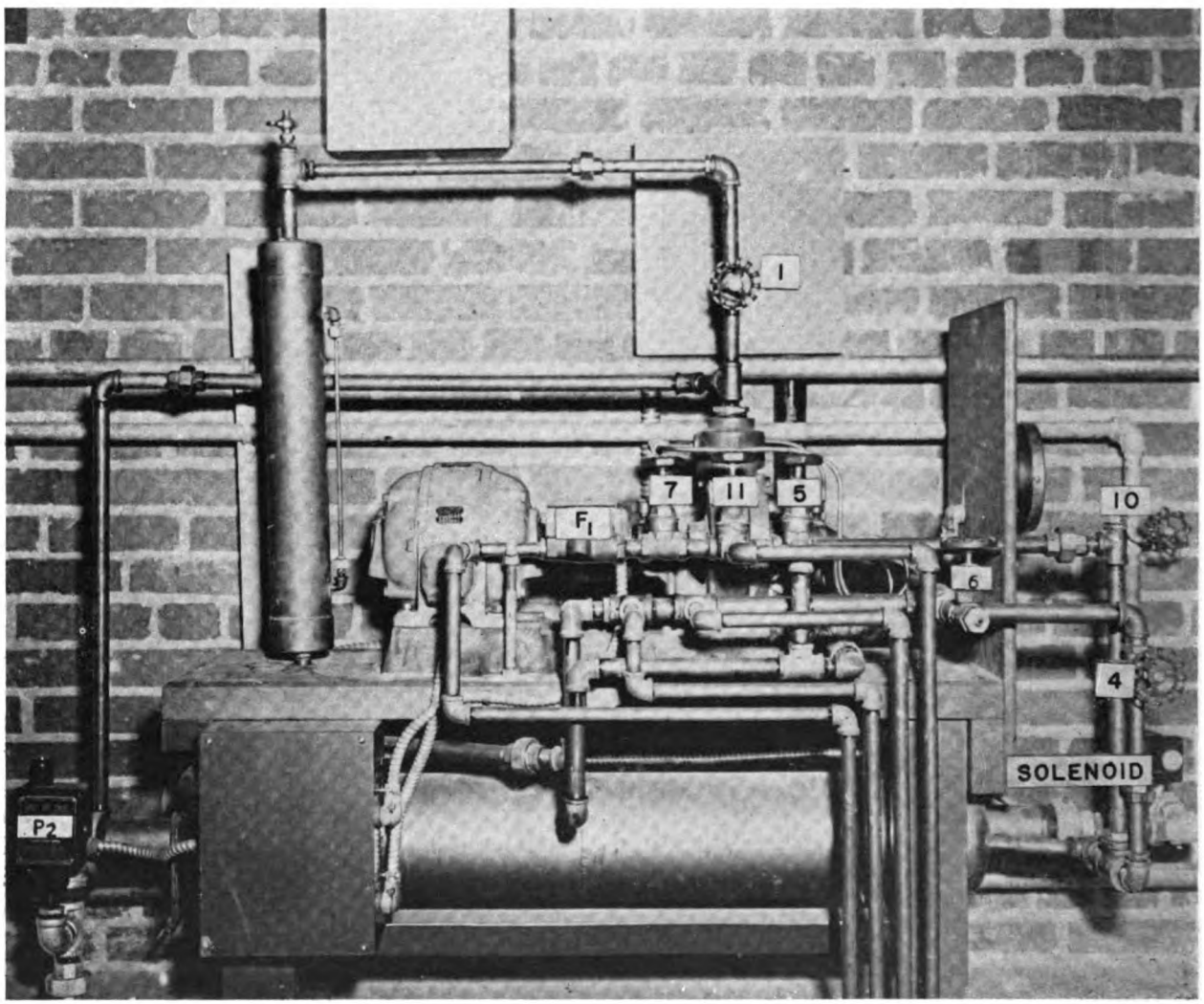
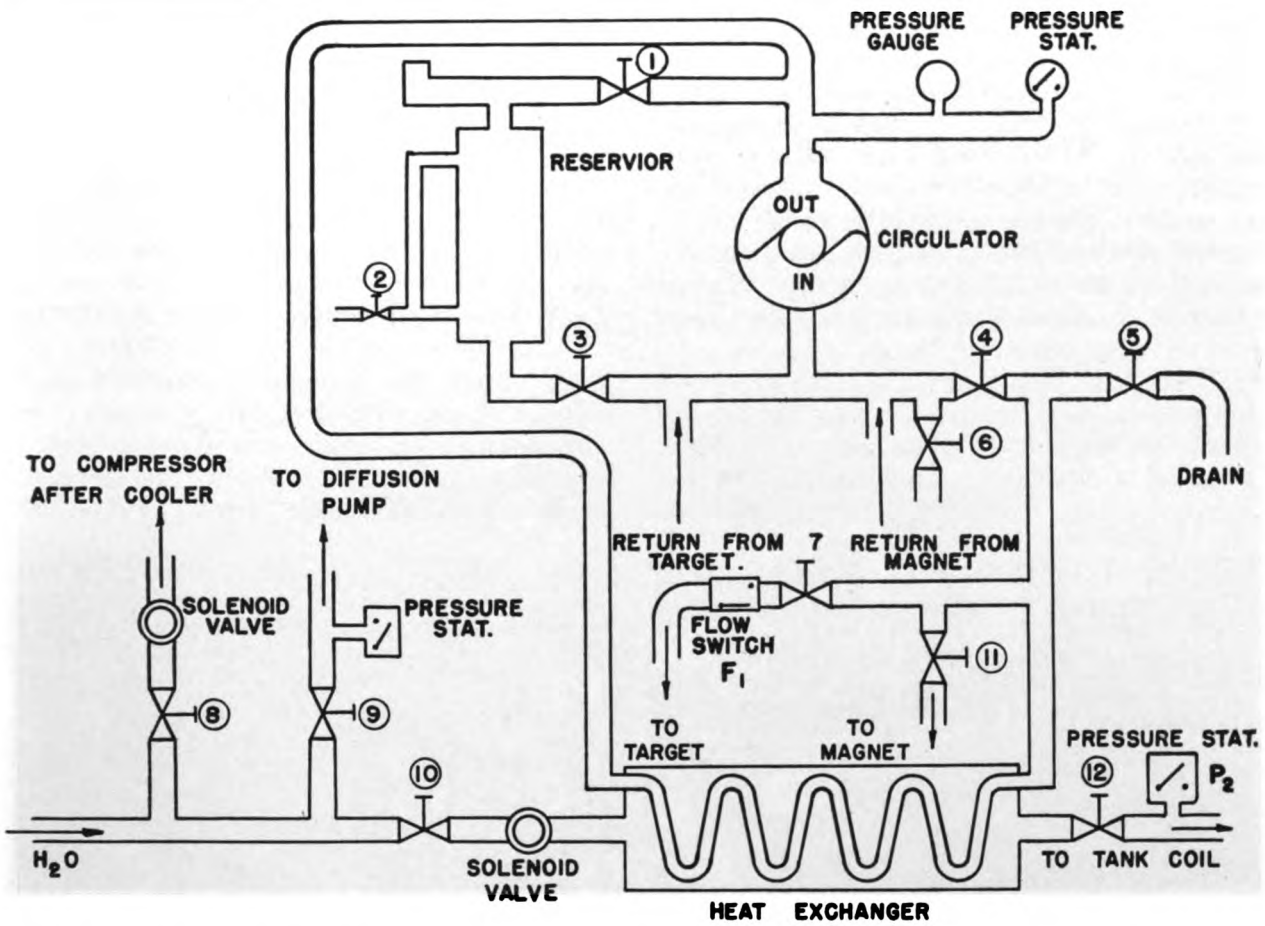


FIGURE 123. Water circulator



VALVES	1	2	3	4	5	6	7	11
TO FILL	X	X	X	X	X	0	0	0
TO DRAIN	X	X	0	X	0	X	X	X

O-OPEN
X-CLOSED

FIGURE 124. Water circulator system

moisture content of a newly installed belt depends largely on how long it has previously been exposed to the wet atmosphere, some belts may require even longer drying periods. If necessary, circulation should be continued for several days, preferably with the belt running to allow more moisture to be expelled. This may be done while exposures are being made and therefore need not cause interruption of regular generator operation.

After each pumping up or circulating period, it is important to warm the CO_2 cooling coil to room temperature and allow any *trapped* water to drain from the system. The silica gel should always be properly dried just prior to pumping air into the tank from atmospheric pressure, with sufficient time having been allowed for cooling to room temperature. This requires about 6 to 8 hours. Otherwise the gel should be dried about once weekly to regenerate it fully after it has been used to care for normal daily tank leakage. A thermostat control unit is installed in the silica gel exhaust line to turn off automatically the heater element and compressor when the temperature of the silica gel has risen to 240°F. A pressurestat is also provided to turn off the compressor when the tank has reached 200 lbs. pressure.

The control switches for the compressor and heating element are located at the relay cabinet. For the detailed electrical circuit, refer to Figure 121. The diagram, Figure 125, shows the

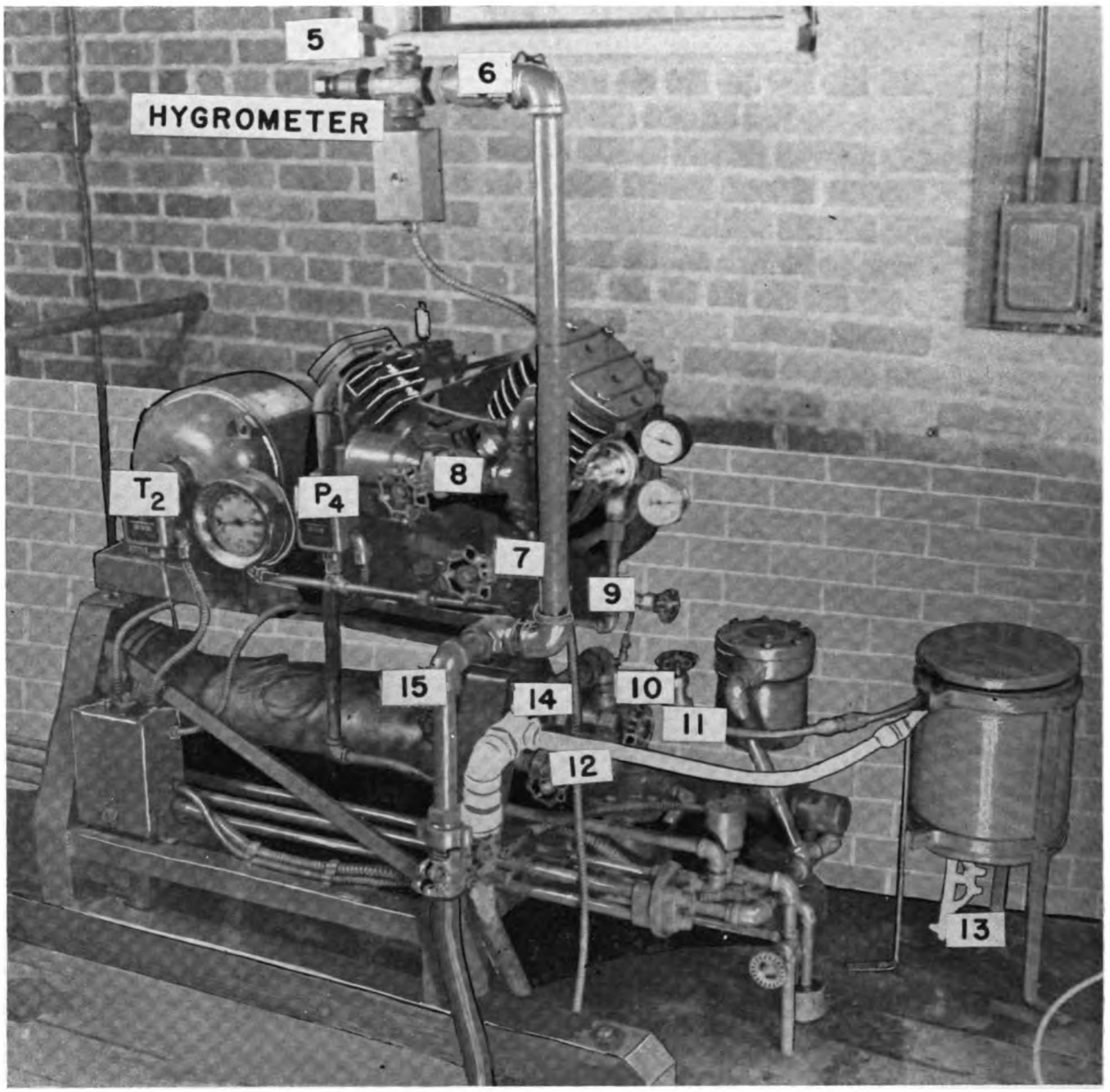


FIGURE 125. Compressor

position of the various units in the system, while the operation chart provides a guide in showing the valve positions for the specified operations. The blank spaces in the chart indicate those valves which are not involved in the operation indicated.

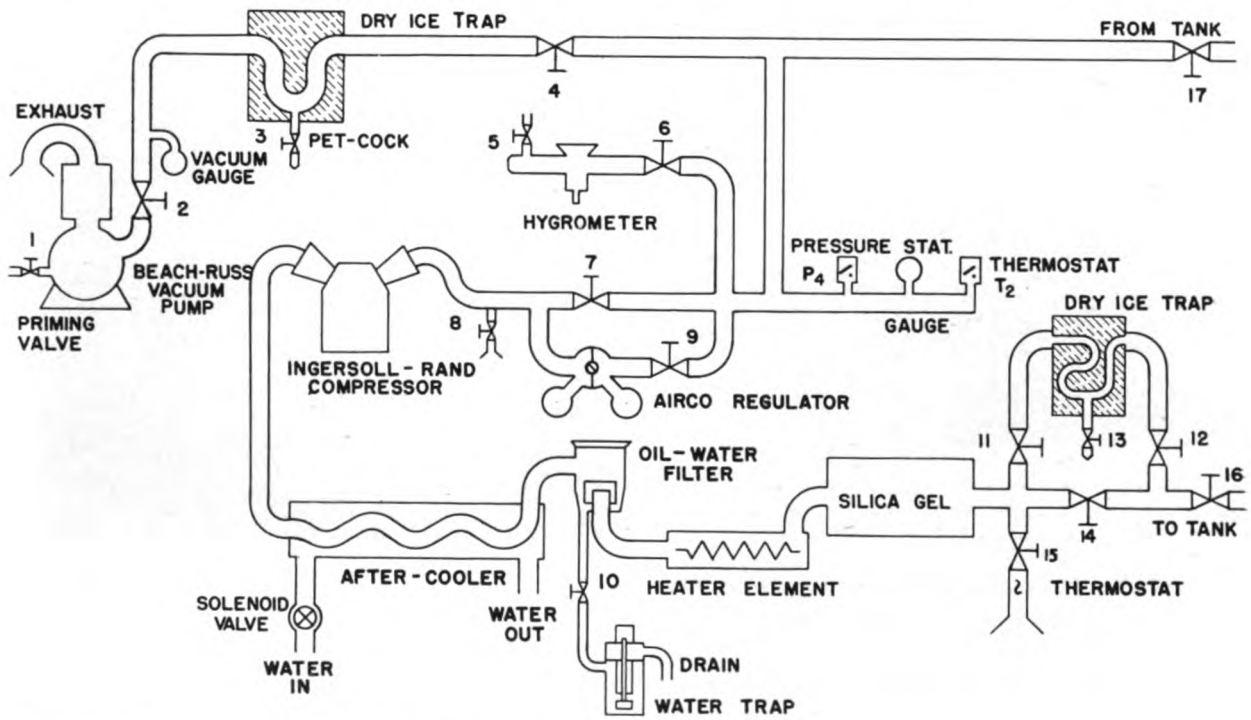
The compressor and motor should be serviced regularly according to the monthly check list. The oil should be replaced every 500 hours of operation; use SAE 20. Check belt tension; the belt should vibrate when struck with the hand. Keep cooling fin clean by blowing off with air once a month. Extreme caution is required when using air hose with compressor. The air should not be directed toward anyone nor the end left untended.

The Beach Russ Pump

For the initial treatment in drying the tank and getting moisture out of the belt lining it is

most efficient to pump out the tank air first. This is done by the Beach Russ Evacuating Pump. This pump is connected to the tank through a U-shaped trap and may be isolated from the compressor system by means of valves when the compressor is in use. (See compressor diagram—Figure 126.) A vacuum gauge attached to the line to the tank indicates vacuum pressure. Whenever his pump is started, it should not be left unattended until a 30 inch vacuum is indicated on the gauge. The pump should not be stopped during the evacuation because the oil in the pump reservoir might be sucked into the air line. The oil trap beneath the deck prevents oil from getting into the tank should the pump stall. Each time the tank is evacuated, the box surrounding the U-shaped dry ice trap should be filled with chopped dry ice to provide a cold spot for trapping water present in the tank air. Immediately after each evacuating period, this trap should be warmed to room temperature and the trapped water allowed to drain from the pet-cock at the bottom of the U. After the evacuating period which is approximately 3 to 4 hours for the quickest and most efficient drying, the compressor system should be pumped to 200 pounds pressure, and the inlet valve to the tank No. 11, cracked just enough to drop the system pressure to about 150 pounds. The compressor is again started and this valve kept in adjustment to maintain this pressure until the tank is pumped up. In this way, air is kept under pressure in the silica gel container and cooling coil just before entering the tank, thereby more efficiently removing moisture.

For the electrical circuit controlling the operation of the pump, see Figure 121. The con-



OPERATION	VALVE NUMBERS																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TO PUMP UP TANK				X		X	X	O	X	O	O	O	X	X	X	O	X
TO EVACUATE TANK	X	O	X	O		X	X		X			X		X		X	O
TO CIRCULATE TANK				X		X	X	X	O		O	O	X	X	X	O	O
TO DRY SILICA GEL							X	O		O	X			X	O		

AIR DRYING SYSTEM | NO. FIG. 2

FIGURE 126. Air drying system

trol switches are mounted on the pump. Figure 127 shows Beach Russ Vacuum Pump installed.

The Beach Russ Pump requires a certain amount of servicing to insure dependable operation.

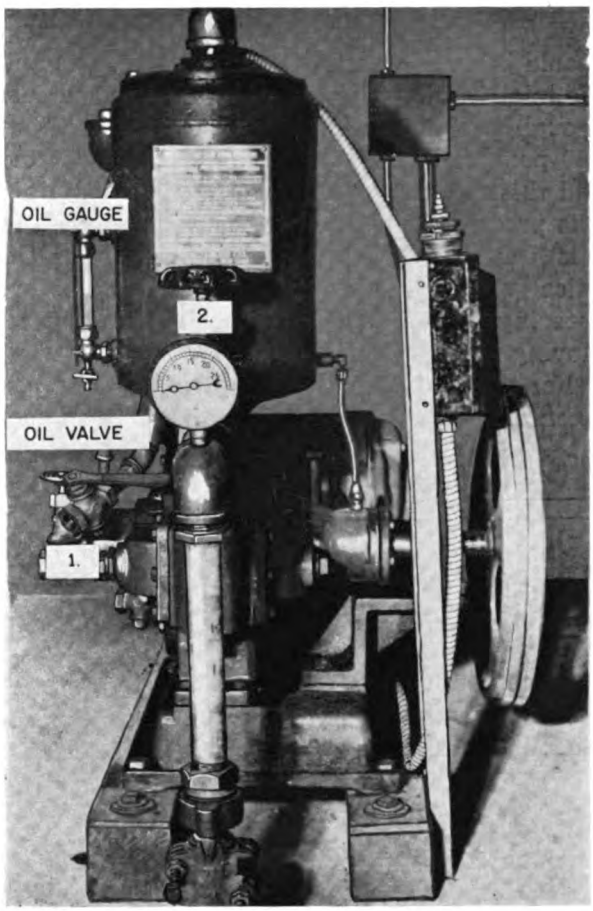


FIGURE 127. Photograph of Beach Russ Vacuum Pump showing valves, gauges, and mounting of start-stop switch box

The oil should be changed once a year to prevent wear on the pump. Pennsylvania Pacemaker #3 SAE 30 manufactured by Cities Service Oil Co., or its equivalent, should be used to refill.

When starting pump always turn the fly wheel over by hand to be sure it is full. Open oil valve to lubricate pump, also valve No. 1 which is a vent or pumping valve. Start the pump by means of the electric switch. When it gets up to speed, secure valve 1. When shutting down, close oil valve five minutes before stopping pump. Then open valve No. 1 two minutes before securing; this pumps the oil back into the reservoir and prevents the pump from locking.

If the pump becomes locked, drain the oil and turn the flywheel by hand until the pressure is released.

Batteries and Battery Charger

The Lens Batteries are standard lead acid type batteries. The fully charged specific gravity is 1.206 to 1.290. The batteries should never be allowed to discharge below 1.100. When taking specific gravity readings hold hydrometer vertically and tap lightly so that the float does not stick. Only charge he batteries that are being used and not the whole bank. See Figure 130 for complete lens battery circuit.

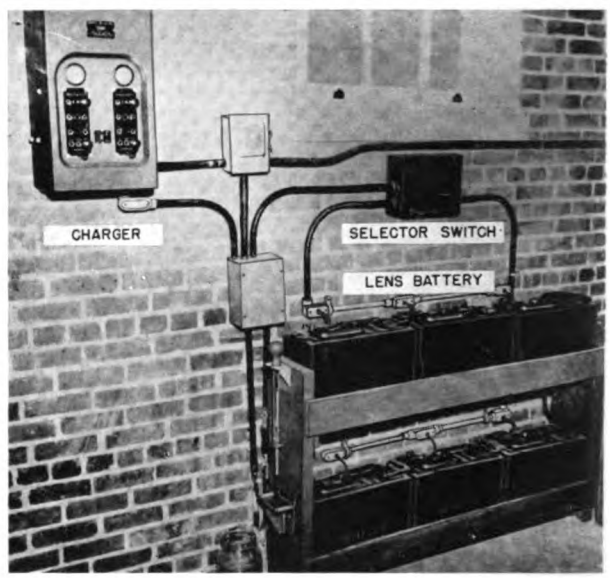


FIGURE 128. Photograph of charger and battery installation for Generator No. 3

The General Electric Tungar Battery Charger is used to charge the batteries. The wiring diagram is shown in Figure 129. The tungar tubes should be tightened occasionally to insure good contact. The charger is turned on at the control panel; the switch on the charger can then be thrown. This will light the tungar tubes, but the ammeter does not read until the five adjustment plugs are put in place. These are adjusted so that the ammeters read the same. The charging current is the sum of

the two ammeter readings. When charging the Diesel engine batteries, be sure the batteries are not connected to the Diesel starter.

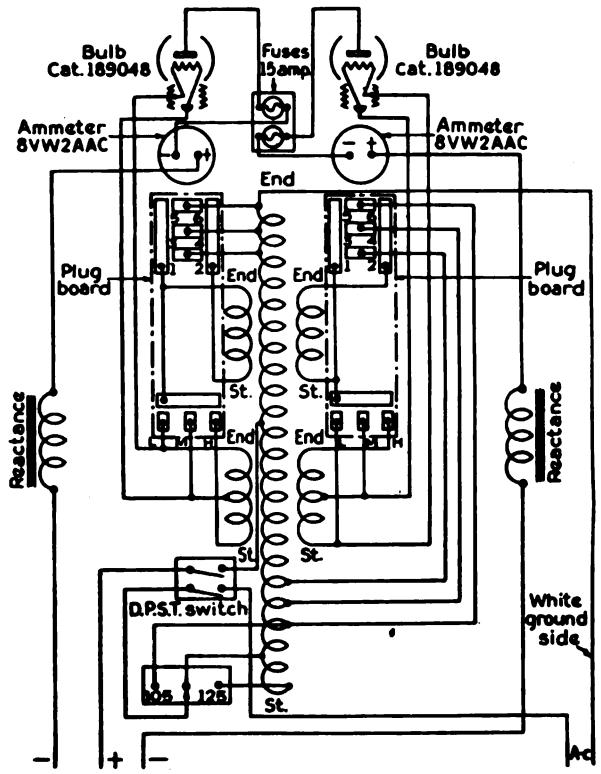


FIGURE 129. Connections of 115-volt Tungar, auto-transformer type charger

High Voltage Transformer

The 75 KV voltage transformer rectifier is build by Campbell X-ray Corporation. The circuit is shown in Figure 131. When servicing the transformer, the bolts must be loosened and the cover raised. The condenser, transformer, and tube are attached to the cover. The high voltage lead is insulated with petroleum jelly. Never energize the circuit when it is possible for personnel to come in contact with the high voltage lead.

Vacuum System

The installation of the sealed-off x-ray tube developed by the Machlett Laboratories eliminates the necessity of the vacuum system here described except as a stand-by in emergency.

The vacuum system consists of the tube, tube lead with valve, mercury diffusion pump and HyVac mechanical pump. The volume of the system is 10 liters. The pressure for operation is 1×10^{-6} mm. Hg. The valve separating the tube from the system is a sylphon type and should not be closed tightly or opened all the way. When disassembling pumping lead, this valve should be open.

The sketch of the diffusion pump is shown in Figure 132.

The mercury is vaporized by the heater and condensed when it rises and strikes the cold plate; this plate is kept at –76° C. by the dry ice (CO_2) in the trap. When the mercury vapor condenses, it carries the gases out of that region through the jets into the fore vac region where they are pumped to the outside by the fore vac pump. The McLeod gauge in the vacuum system is connected both to the fore vacuum region and the high vacuum region. The diffusion pump does not begin to operate until the fore vac pressure is down to .1 mm mercury. The cooling coil around the diffusion cools the mercury after it condenses.

If the dry ice trap becomes empty, secure the heater and close the main tube valve. Never leave the heater on without cooling water in the coil and dry ice in the trap.

If a leak is suspected in the tube, take a vacuum reading and close the tube valve for 20 minutes. If the vacuum improves, the leak is in the tube side. Then open the valve and take a vacuum reading after the system has come into equilibrium, which should take place within 4 seconds.

When letting air into the tube use the small valve in the sylphon valve bonnet. Attach a liquid air trap and immerse in a flask of liquid air; then crack valve and allow the air to flow in slowly taking approximately five minutes to completely equalize the pressure.

When pumping out after being open, attach a fore vac pump to the small valve and pump for about 15 minutes. The Beach Russ Pump can be used for this. Also the HyVac pump in parallel can be used. When opening the sylphon valve watch the McLeod gauge. If the pressure in one region is greater than the other it will cause the mercury in the Y to be pulled into the low pressure side. The best policy is to lower the mercury pot so that the mercury level is below the Y.

Figure 133 shows the mercury level in the

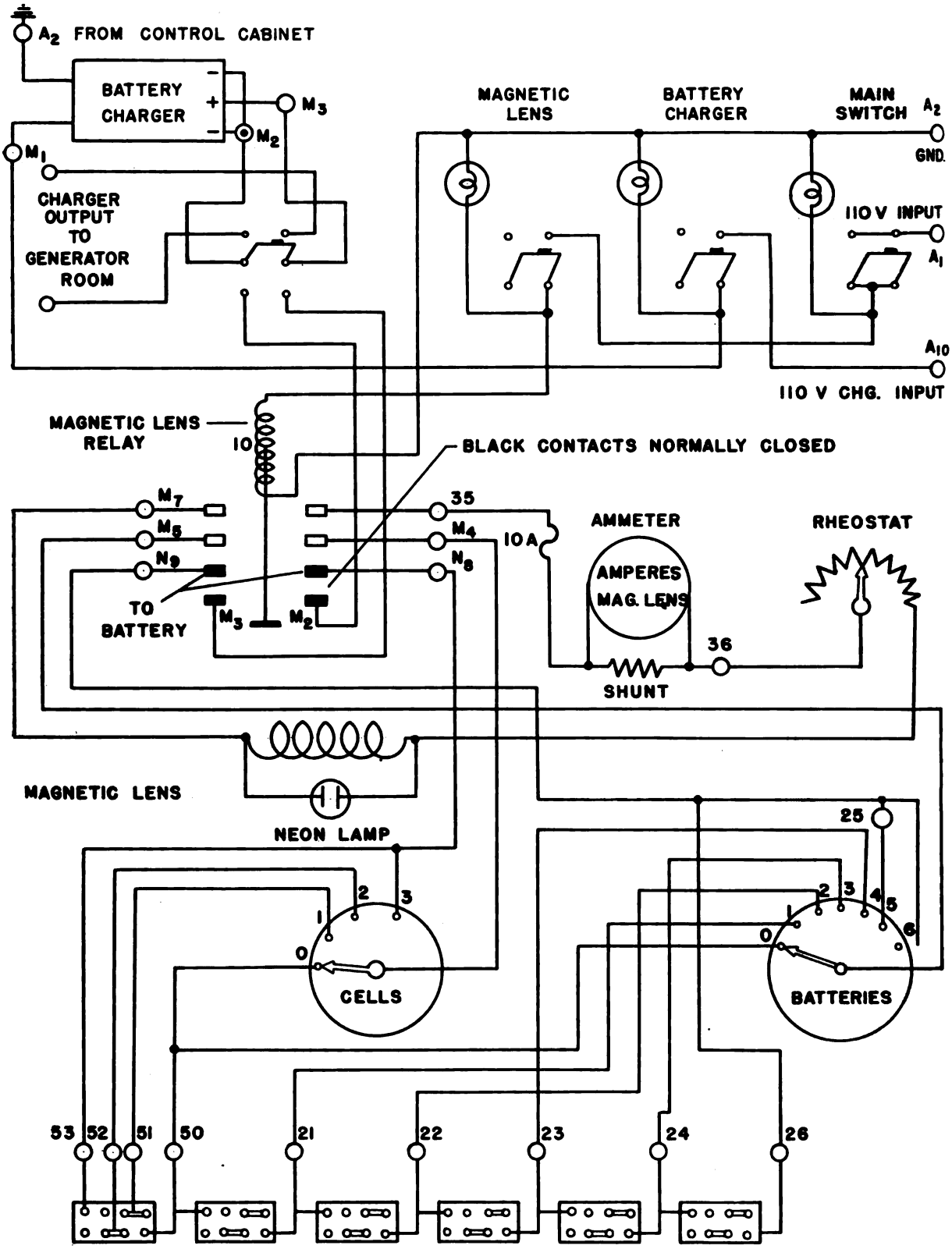


FIGURE 130. Wiring for magnetic lens circuit

diffusion pump. This should be maintained at 1½ inches above the top of the heater as shown. The level is checked by radiographing the pump with the radium camera. The technique is A film, 3 feet, 90 minutes. This check should be made monthly to insure good operation of the vacuum pump. The dry ice trap should be cleaned monthly by taking out the ice and heating with air gun until all the ice is melted. This will insure good contact between dry ice and trap.

If the mercury level is found low (Figure 134), then close the main tube value and secure heater and fore vac pump. Remove the dry ice and heat the trap; let the air into vacuum

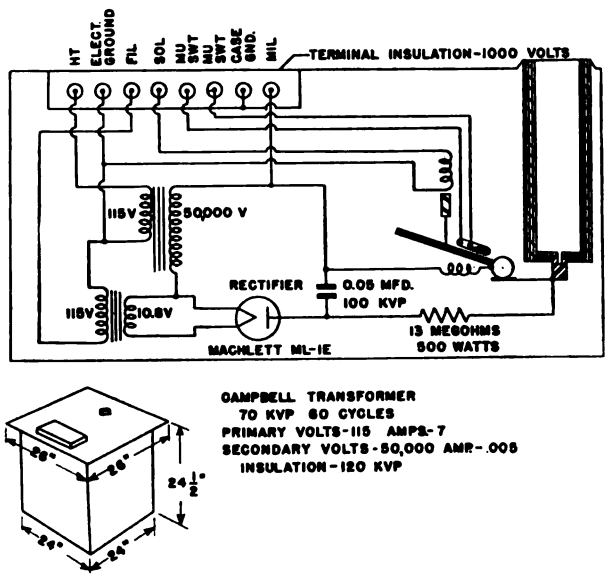


FIGURE 131. 70,000 volt power supply

system through the liquid air trap. Remove the McLeod gauge and store in safe place; then remove long bolts holding the diffusion pump together, being careful of gaskets. The top can now be removed. When the mercury is replaced, reassemble the pump as soon as possible; clean each part thoroughly.

Vacuum Trouble Sheet

In the event of faulty vacuum conditions in the generator, a systematic check can be made. This will progressively eliminate potential sources of trouble and use a minimum of time. The trouble sheet is composed of two sections as follows:

699810—46—9

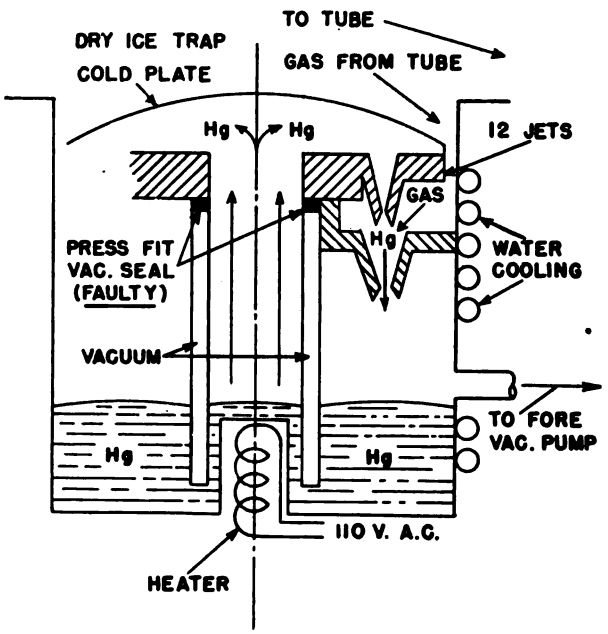


FIGURE 132. Mercury diffusion pump

(1) Troubles with the vacuum pumping system

(2) Troubles with the x-ray tube itself

Whenever there is evidence of poor vacuum, the main value should be closed to check the condition of the pumping system. Close attention should be paid to both the high vacuum and the fore vacuum. The fore vacuum could eventually affect the high vacuum. On the other hand, a leak in the system would result in the diffusion pump discharging more gas into the fore vacuum, thus raising the fore pressure.

If the fore vacuum is all right, but the high vacuum is faulty, the diffusion pump heater may be the cause of the trouble. To check this, a continuity test of the heater (if the boiler is cold) should be made. The power input to the heater should be about 275-300 watts. If the heater is faulty in any way, it should be replaced.

Vapors may be the reason why the vacuum is not adequate.

A quick check on a bad vapor condition is to put liquid air into the two glass traps over the McLeod gauges. If a cloudiness is observed in either the fore- or high-vacuum line, steps should be taken to remove the vapors. For vapors in the high vacuum line, placing a liquid

air trap in the fore vacuum line is sometimes helpful. In extreme cases, liquid air can be put into the diffusion pump trap, but usually this step should not be taken. If the pumping system is that dirty, it should be disassembled, cleaned, and new mercury put in.

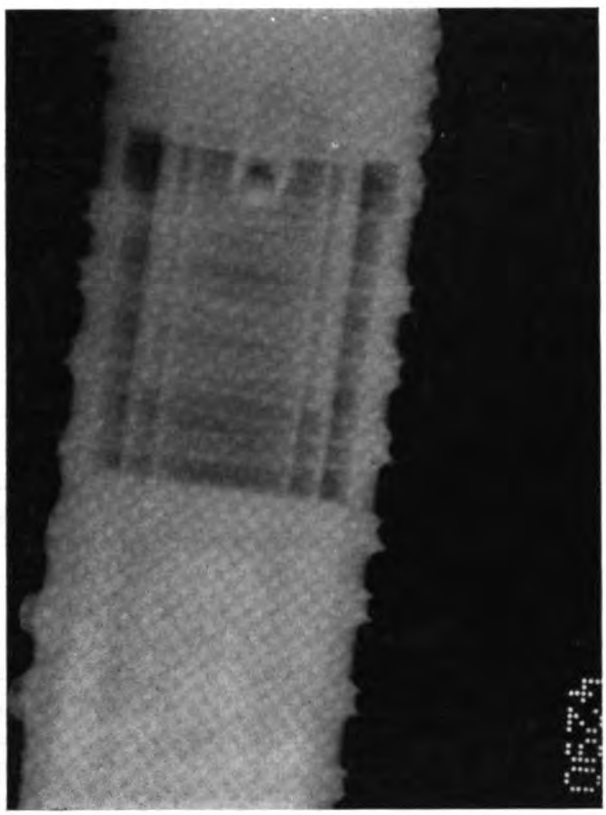


FIGURE 133. Radiograph of mercury diffusion pump showing mercury at proper level

The pump itself may leak. The various check gaskets should be tested with 200 pounds pressure or with a vacuum, and the bolts should be tightened if necessary. In the event that the gaskets still appear to leak, the pump should be taken apart and new gaskets installed.

The mercury of the diffusion pump may be collected on the dry ice trap, or may be trapped elsewhere. A radiograph can be made of the pump.

If the vacuum is still faulty, the pump should be taken apart, cleaned, and new mercury used. The system then must be completely checked because of the possibility of new sources of trouble.

In the event of a poor fore vacuum, the first check should be to examine the HyVac protective. If it has been tripped, it must be reset and the pressures read after equilibrium has set in. If the fore pressure is still poor or if the protective has not been actuated, there may be a leak in the rubber hose or oil trap between the diffusion pump and the HyVac. This can be checked quickly by noticing the change in the sound of the HyVac when the hose is pinched off at (1) the diffusion pump, (2) at the oil trap on the mercury pump side, (3) at the oil trap on the HyVac side, and (4) at the HyVac itself. If the sound changes to a light "clacking" in Step 1, the line is all right. If not, try positions 2, 3, and 4; if the sound change occurs at any of these positions, there is a leak in the line between that station and the diffusion pump. In the event that there is no change in sound wherever the line is pinched, the HyVac may be faulty.

The HyVac oil level may be low. The top of the HyVac should be removed and enough oil

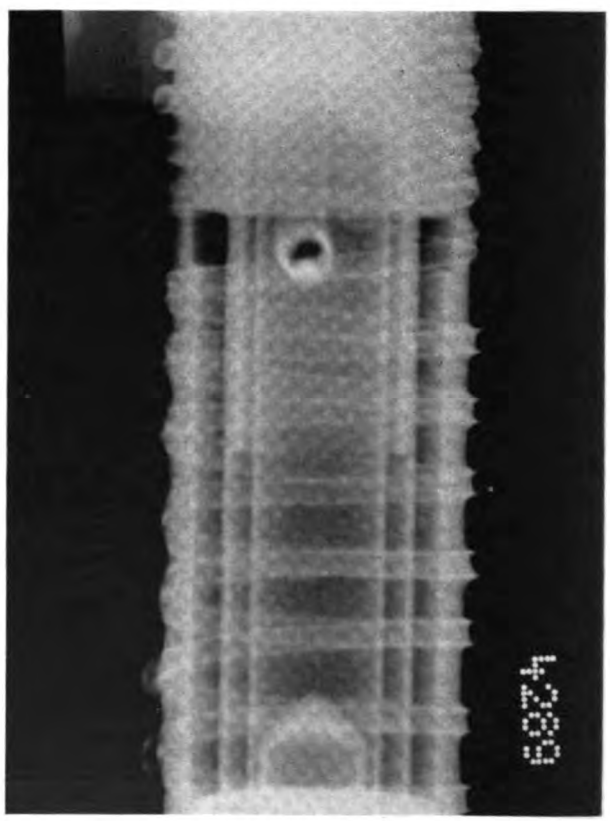


FIGURE 134

poured in to bring the level up to the indicated mark on the side of the pump. Sometimes the oil becomes contaminated with water or solvents, thus affecting the performance of the pump. To check against this eventuality, new oil should be installed. If a spare HyVac is at hand, the pump can be replaced immediately when it is suspected. At leisure, the questionable pump can be inspected.

By checking the McLeod gauges with liquid air in the glass traps as outlined above, the vapor condition can be checked.

The order of the check on the trouble sheet allows the condition of the pumping system to be ascertained much more quickly than if a random series of tests is made. Sometimes the trouble can be isolated almost immediately because of the systematic elimination of causes.

Once the condition of the pumping system has been found to be adequate, the main valve is opened to check the entire system. If the vacuum is still adequate, the generator may be fired up again. If the vacuum becomes bad after opening the valve, the trouble is in the system on the tube side of the valve and must be isolated by a series of eliminations.

To avoid the necessity of letting the air out of the tank, thereby losing a great deal of time in pumping up and drying, it is considered worth while to check all joints outside the pressure region even if the leak is suspected in the generator itself. The lower check gasket of the x-ray tube, which is connected to atmospheric pressure by a Saran tubing, should be tested by evacuating with either the HyVac or the Beach Russ pump. If the high vacuum improves, the gasket is faulty and must be repaired. For emergency use, however, it may be that evacuating the gasket reduces the leak so that the tube vacuum is adequate for running. In this case, the pump should continue to evacuate the guard ring.

If this check gasket has been found to be all right but the vacuum continues to be inadequate, the target check gasket, the target water jacket, the pumping lead gaskets, and the main valve bonnet should all be checked either with 200 lbs. pressure or with a vacuum. If any changes in the vacuum condition are noted in this check, steps should be taken along the lines of the recommendations of the sheet on Special Guard Ring Tests.

The tank pressure should be dropped to atmospheric pressure only if no leak has been detected outside the tank.

As the tank pressure drops, the vacuum should be observed. If the vacuum improves with decreasing pressure, there is undoubtedly a leak in the system in the tank. If the vacuum does *not* improve, however, there may be a leak inside, but it is more unlikely. Before removing the tank, it would be advisable to take stock of the tests conducted before, to make sure that all possibilities were considered. Here again, much time may be saved by spending a little more time on the condition of the system outside the tank.

The lower check gasket should be checked again, this time with pressure. If it is faulty, it should be repaired according to the Special Gasket Check. The various gaskets of the cathode assembly are next tested, and the cathode replaced if there is evidence of a leak in the pressure pot or if the check gasket cannot be made tight.

If the vacuum still remains poor, the x-ray tube should be removed and the tube extension blanked-off. The tube column is probably faulty if the vacuum becomes better after this step, and should be replaced by the spare column. In installing the new tube and cathode, of course, the entire system must be checked again.

With the tube extension blanked-off and with the vacuum still poor, the blank-off plate or the tube extension may leak. The former may be checked according to the Special Gasket Check, and, if all right, the latter may be tested by replacing the tank, pumping up to 200 lbs pressure, and observing the vacuum. Before this test, which is time consuming, the pump should be rechecked to be sure that it has not become contaminated by vapors as a result of opening the vacuum system. If the vacuum becomes poorer as the tank pressure rises, the trouble is in the tube extension, assuming that the blank-off plate gasket is connected to atmospheric pressure. The welded joint in the tube extension may have parted. If a spare extension is at hand, it should not be used until

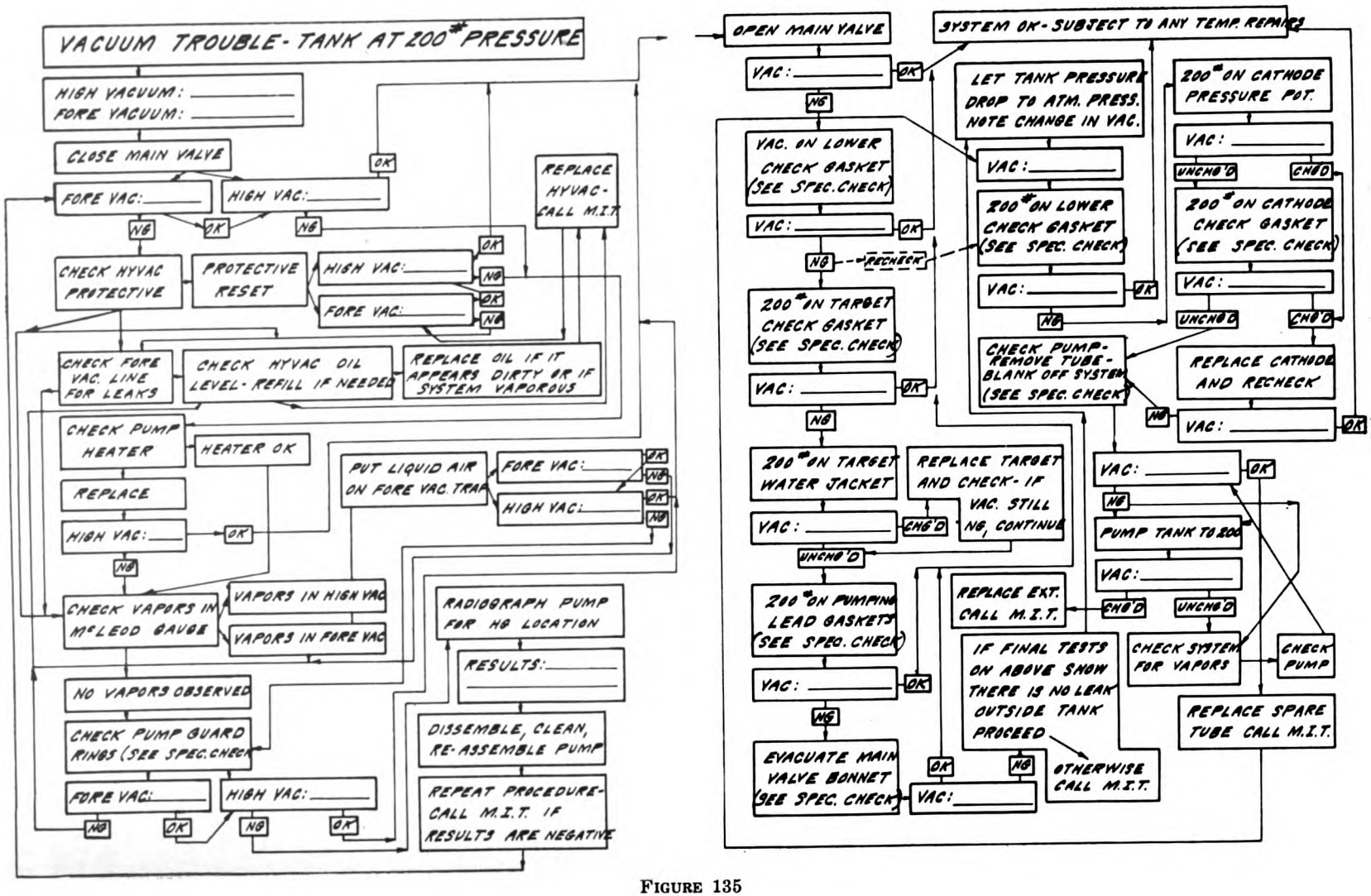

VACUUM TROUBLE - TANK AT 200# PRESSURE
HIGH VACUUM: _____
FORE VACUUM: _____
CLOSE MAIN VALVE
FORE VAC: _____
HIGH VAC: _____
OK
NG
REPLACE HYVAC - CALL M.I.T.
CHECK HYVAC PROTECTIVE
PROTECTIVE RESET
HIGH VAC: _____
FORE VAC: _____
CHECK FORE VAC. LINE FOR LEAKS
CHECK HYVAC OIL LEVEL - REFILL IF NEEDED
REPLACE OIL IF IT APPEARS DIRTY OR IF SYSTEM VAPOROUS
CHECK PUMP HEATER
HEATER OK
REPLACE
HIGH VAC: _____
PUT LIQUID AIR ON FORE VAC. TRAP
FORE VAC: _____
HIGH VAC: _____
CHECK VAPORS IN McLEOD GAUGE
VAPORS IN HIGH VAC
VAPORS IN FORE VAC
RADIOGRAPH PUMP FOR HG LOCATION
RESULTS: _____
NO VAPORS OBSERVED
CHECK PUMP GUARD RINGS (SEE SPEC. CHECK
DISSEMBLE, CLEAN, RE-ASSEMBLE PUMP
FORE VAC: _____
HIGH VAC: _____
REPEAT PROCEDURE - CALL M.I.T. IF RESULTS ARE NEGATIVE
OPEN MAIN VALVE
VAC: _____
SYSTEM OK - SUBJECT TO ANY TEMP. REPAIRS
VAC. ON LOWER CHECK GASKET (SEE SPEC. CHECK)
LET TANK PRESSURE DROP TO ATM. PRESS. NOTE CHANGE IN VAC.
200# ON CATHODE PRESSURE POT.
VAC: _____
UNCHG'D
CHG'D
200# ON LOWER CHECK GASKET (SEE SPEC. CHECK)
200# ON CATHODE CHECK GASKET (SEE SPEC. CHECK)
RECHECK
200# ON TARGET CHECK GASKET (SEE SPEC. CHECK)
CHECK PUMP - REMOVE TUBE - BLANK OFF SYSTEM (SEE SPEC. CHECK)
REPLACE CATHODE AND RECHECK
200# ON TARGET WATER JACKET
REPLACE TARGET AND CHECK - IF VAC. STILL NG, CONTINUE
PUMP TANK TO 200
200# ON PUMPING LEAD GASKETS (SEE SPEC. CHECK)
REPLACE EXT. CALL M.I.T.
IF FINAL TESTS ON ABOVE SHOW THERE IS NO LEAK OUTSIDE TANK PROCEED
OTHERWISE CALL M.I.T.
CHECK SYSTEM FOR VAPORS
CHECK PUMP
REPLACE SPARE TUBE CALL M.I.T.
EVACUATE MAIN VALVE BONNET (SEE SPEC. CHECK)

FIGURE 135

it is decided definitely that the extension is the source of the leak.

If close attention is paid to the order of checking the vacuum system, the leak should be able to be found with a minimum of effort and with reasonable certainty. Naturally, there are obscure causes that are not included and troubles which have not been experienced, but for routine work, this system of checking should be an adequate guide for most troubles.

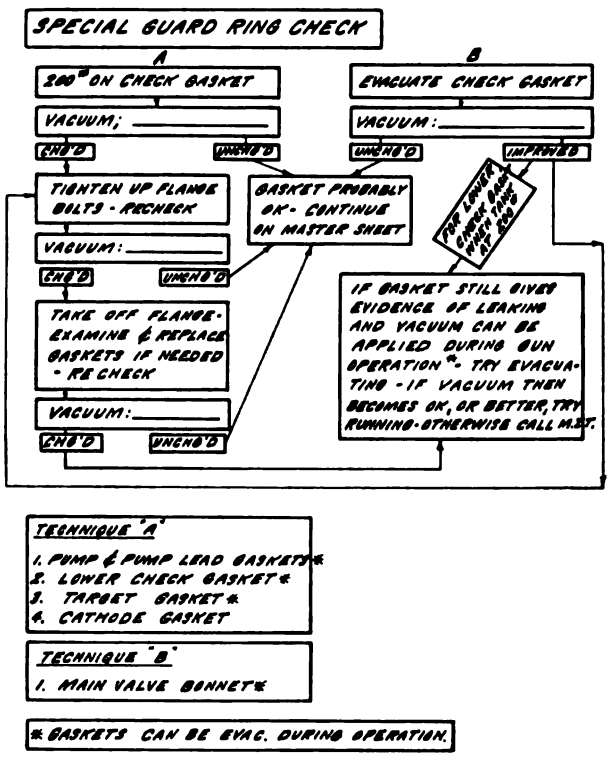

SPECIAL GUARD RING CHECK
A
200° ON CHECK GASKET
VACUUM:
CHG'D
UNCHG'D
TIGHTEN UP FLANGE BOLTS - RECHECK
VACUUM:
CHG'D
UNCHG'D
TAKE OFF FLANGE - EXAMINE & REPLACE GASKETS IF NEEDED - RE CHECK
VACUUM:
CHG'D
UNCHG'D
B
EVACUATE CHECK GASKET
VACUUM:
UNCHG'D
IMPROVED
GASKET PROBABLY OK - CONTINUE ON MASTER SHEET
IF GASKET STILL GIVES EVIDENCE OF LEAKING AND VACUUM CAN BE APPLIED DURING GUN OPERATION * - TRY EVACUATING - IF VACUUM THEN BECOMES OK, OR BETTER, TRY RUNNING - OTHERWISE CALL M.I.T.
TECHNIQUE "A"
1. PUMP & PUMP LEAD GASKETS*
2. LOWER CHECK GASKET*
3. TARGET GASKET*
4. CATHODE GASKET
TECHNIQUE "B"
1. MAIN VALVE BONNET*
* GASKETS CAN BE EVAC. DURING OPERATION.

FIGURE 136

TABLE XXXIII
TROUBLE SHEET

I. X-ray Generator

A. Starting up

1. Voltmeter does not operate (Main Switch thrown)
   (See Generating Voltmeter check—II,A)
2. Water circulator does not operate (Main Switch thrown)
   (See Water Circulator check—II,C)
3. No cooling water through tank cooling coil (Main Switch thrown)
   Cause: No input voltage to solenoid valve
   Tests: Check input to Relay #5-CP, A-1 to gnd. 110 V.
4. Slave selsyn in tank does not operate. (Main Switch thrown)
   Cause: No input voltage.
   Tests: Check input to Relay #5-CP, A-1 to gnd. 110 V.
   Check voltage at power flange, B-14 to gnd. 110 V.
   Check voltage in lead in tank to gnd. 55 V.
5. Driving motor does not start (Main Switch thrown)
   a. At any station (either RC or CP Motor Switch thrown)
      Cause: Cooling water pressure too low.
      Test: Check Water Circulator (See II,C) 45 P.S.I
      Cause: Circulator relay not thrown.
      Test: Check Water Circulator (See II,C)
      Cause: Thermals in Motor Starter #3 kicked out.
      Test: Check thermals—reset starter.
   b. From Control Panel (CP Motor Switch thrown)
      Cause: RC interlock on RC operation.
      Test: Throw RC interlock to CP operation.
      Cause: No input voltage to starter.
      Test: Check input to Relay #3-RC, A-8 to gnd. 110 V.
   c. From Relay Cabinet (RC Motor Switch thrown)
      Cause: RC interlock on CP operation.
      Test: Throw RC interlock to RC operation.
      Cause: No input voltage to starter.
      Test: Check input to Relay #3-RC, A-5 to gnd. 110 V.

B. Shutting down

1. Battery charger does not operate. (Battery Charger Switch thrown)
   Cause: Lens Current Switch still on.
   Test: Turn Lens Current Switch off.
   Cause: No input voltage.
   Tests: Check input, A-10 to gnd., also M-1 to gnd. 110 V.
   Check fuses on A-10.
   Cause: Rectifier burned out.
   Test: Check—replace if necessary.
2. Cooling water still flows through tank cooling coil (all switches off)
   Cause: Cooling protective Relay #2-RC thrown.
   Test: Check Relay—also check room and water temperatures.
   Cause: Thermostat T-1 set too high.
   Test: Check—reset to 32° F—no lower.
3. Alarm horn blows (Main Switch on, all other switches off)
   Cause: Resistor current flowing.
   Test: Check I_R meter reset Relay #6-CP.

Cause: Surge in I_R line trips Relay #6-CP.
Test: Check I_R circuit for surges, if neon lights.

C. Operation
1. Lens current not observed (Main Switch and Lens Current Switch thrown)
Cause: No input to Relay #10-CP.
Test: Check input, A-1 to gnd. 110 V.
Cause: Batteries not connected properly.
Test: Check battery circuit. DPDT Relay.
Cause: Lens Current meter faulty.
Test: Check meter. Shunt X2.
Cause: Magnet fuses blown.
Test: Check fuses on M-6 and M-7 in CP.
Cause: Leads not connected into tank.
Test: Check connections at power flange.
2. Generator sparking (as a function of voltage).
Cause: "Wet" belt.
Test: Check dewpoint, –50° C,—circulate air if necessary.
Cause: Spark gaps (tube and/or equipotential) too close.
Test: Check with spark gap gauge. 125"
Cause: Charging belt poor insulator.
Test: Observe belt condition—if frayed or cut, replace.
3. Generator Sparking (as a function of charging current)
Cause: "Wet" belt.
Test: Check dewpoint, –50° C—circulate air if necessary.
Cause: Charging current circuit faulty.
Test: See Charging Current Circuit check —II.B.
Cause: Charging belt poor insulator.
Test: Observe belt condition—if frayed or cut, replace.
4. Generator sparking (as a function of target current but *not* as a function of load).
Cause: X-ray tube faulty.
Test: See X-ray tube check—III.
5. Performance during running of generator (see special list.)

D. Miscellaneous
1. Tank lights do not operate (Tank light switch thrown)
Cause: No input voltage.
Tests: Check input T—1 to gnd. at power flange. 110 V.
Check voltage in leads in tank to gnd.
Cause: Fuse blown.
Test: Check fuse on T-1 in RC.
Cause: Lights burned out.
Test: Check lights—replace if necessary.
2. Vacuum pump heater not on (Vacuum Pump Switch thrown).
Cause: No input voltage.
Test: Check input at pump, B-18 to gnd. 110 V.
Cause: Fuses blown.
Test: Check fuse on B-18 in RC.
Cause: Heater faulty.
Tests: Check continuity of heater.
Check power input to heater, 3 amps, (should be 275-300 watts).
3. Air compressor does not operate. (Compressor Switch thrown and Start Button depressed.)
Cause: No input voltage to starter #6-RC.
Test: Check input A-1 to gnd. 110 V.
Cause: Air temperature too high.
Test: Wait for air to cool. 240° F.
Cause: Thermostat set too low.
Test: Check Thermostat T-2, should be 240° F.
Cause: Thermals in Starter #6-RC kicked out.
Test: Check thermals; reset starter.
Cause: Air pressure too high.
Test: Relieve pressure at compressor. 200 P.S.I.
Cause: Pressurestat set too low.
Test: Check pressurestat P-5, should be 200 lbs.
4. Air heater in compressor does not operate (Compressor running; Air Dryer Switch thrown; Air Dryer Start Button depressed).
Cause: Thermals of Starter #5-RC kicked out.
Test: Check Thermals—reset Starter.

II. Auxiliary Apparatus

A. Generating Voltmeter
1. Voltmeter does not function.
a. Motor does not run (Main Switch thrown).
Cause: Voltmeter leads on tank not connected.
Test: Plug in leads in floor receptacle.
Cause: No input voltage.
Tests: Check input, A-5 to gnd. at RC. 110 V.
Check B-14 to gnd. at voltmeter. 110 V.
b. Filaments do not light (Main Switch thrown).
Cause: Filaments burned out.
Test: Replace tubes (6H6).
c. No meter reading (during exposure).
Cause: Relay #11-CP not thrown.
Test: Stop and restart exposure—check Relay contacts.
Cause: Meter faulty.
Test: Check with general purpose auxiliary meter. (See also a and b above).

2. Faulty meter readings (during exposure).
   Cause: One tube burned out.
   Test: Check tubes and replace if necessary (6H6).
   Cause: Current shunted to ground.
   Tests: Check resistance B-8 to gnd. (1) between 1000 MEGS CP and floor receptable and (2) in voltmeter lead on tank.
   Cause: Bias batteries old or defective. 1.5 V.
   Test: Check condition — replace if necessary.

B. Charging Current Curcuit
1. No charging current observed. (During exposure—assuming that correct starting procedure followed. Motor Switch thrown.)
   Cause: No input voltage to power supply.
   Tests: Check input = Variac to interlock, A-7 to gnd. 110 V.
   Check Variac input, A-6 to gnd. 110 V.
   Check Variac output, A-4 to gnd. 110 V.
   Remote control switch on CP must be set for panel operation.
   Cause: Improper relay contacts.
   Tests: Relays #1, 2, 3, 5 and 7-CP should be thrown. Check voltage to gnd. on contacts 5-3, 4; 3-1, 5; 3-4, 8; 2-2, 5; 2-3, 6; 1-1, 3; 1-2, 4; 7-1, 2.
   Cause: Fuses blown.
   Tests: Check fuse on B-9 in RC.
   Check fuse on B-11 in RC.
   Cause: Protectives may be open.
   Tests: Check centrifugal switch on B-9 and B-15.
   Check compressor pressurestat or tank pressure.
   Check pressurestat P-1 on water circulator. (See II,C).
   Check flow switch F-1 on water circulator. (See II,C).
   Cause: Meter circuit faulty.
   Tests: Check I_e meter.
   Check resistance S-1 to gnd. 500 MEGS.
   Cause: Faulty power supply.
   Test: (See below: II, B, 2, 3, 4, 5).
2. Valve filament does not light (Main Switch thrown; main interlock closed; no charging current observed; no filament glow seen).
   Cause: No input voltage.
   Test: Check input, A-1 to gnd., 110 V, at CP (for CP operation).
   Check input, A-5 to gnd., 110 V, at RC (for RC operation).
   Check input, S-2 to gnd., 110 V, at power supply.
   Cause: Fuse blown.
   Test: Check fuse on S-2 in RC.
   Cause: Motor not on (when running from RC).
   Test. Throw RC Motor Switch.
   Cause: Filament burned out.
   Test: Check filament current — replace valve.
3. Suspected leakage (during exposure: erratic or high charging current).
   Cause: Faulty H.V. bushing in power flange.
   Test: Disconnect H.V. lead at spray points and observe I_e. If current noted disconnect cable from power supply and observe I_e. If no current, examine H.V. bushing—replace.
   Cause: Faulty H.V. cable.
   Tests: If I_e noted after above test, disconnect H.V. cable from power supply and observe I_e. If no current noted, replace cable.
   Cause: Faulty power supply insulation.
   Tests: If I_e noted after test above, power supply probably leaks, should be checked internally.
4. Insufficient power supply output. (During exposure; max. Variac setting not adequate for generator requirements).
   Cause: Variac inside CP set too low.
   Test: Raise setting of Variac inside CP 40—50 V.
   Cause: Low line voltage.
   Test: Check line voltage. 110 V.
   Cause: Rectifier valve faulty.
   Test: Check valve filament current.
   Cause: Leakage in H.V. lead.
   Test: (See II,B,3 above).
5. Power supply operation still questionable after above tests.
   Tests: Short H.V. lead to gnd. at spray points and observe I_e. Discussion on power supply includes currents to be expected under these conditions.

   WARNING: On Westinghouse supplies, do not short H.V. lead to gnd. except through series resistor, 11 MEGS. Otherwise, serious damage to the unit is likely to result.

   Campbell supplies have internal series resistor; so the damage is not likely to occur.

C. Water Circulator System
1. Motor does not operate (Main Switch thrown).
   Cause: No input voltage.
   Test: Check input to Relay #5-CP, A-1 to gnd. 110 V.

Check input to Relay #4-RC, A-5 to gnd. 110 V.
Cause: Thermals on Starter #4-RC kicked out.
Test: Check Thermals—reset starter.

2. Insufficient water pressure (Main Switch thrown and circulator running).
Cause: Leakage in circulator system.
Test: Check entire system for leaks. 45 P.S.I.
Cause: Insufficient water in system.
Test: Check water level—fill if necessary (half).
Cause: Water input to pump clogged.
Test: Check.

3. Bubbles in water line (Main Switch thrown and circulator running).
Cause: Air in water line.
Test: Flush out system and replace with distilled water.

III. X-ray Tube

A. Filament Assembly and Circuit

1. No target or emmission current. (During exposure or when circuit being tested.)
Cause: Filament burned out.
Test: Check continuity—replace cathode.
Cause: Filament not grounded.
Test: Check circuit—trans. primary and one side of filament should be grounded.
Cause: Micro-switch on filament transformer faulty.
Test: Check micro-switch with ohmmeter (open when arm is down).
Cause: Filament generator faulty.
Test: Check filament generator output. 6 V.
Cause: Slave selsyn in tank not operating.
Tests: Check resistance B-1, B-2, B-3 to gnd. at power flange in side tank, and at CP. 10 MEGS. (See also I, A, 4).
Cause: Filament current control rod faulty.
Test: Check rod—may be loose, unconnected, or broken.
Cause: Filament shorted to cup.
Test: Check filament leads with megohmmeter — 1,000 MEGS. — replace cathode if necessary.

2. Low max. target or emission current (during exposure or when circuit is tested).
Causes: Filament shorted to cup.
Filament lead resistance to gnd. too small—1000 MEGS.
Tests: Check filament leads with megohmmeter. Replace cathode if necessary.
Cause: High resistance in filament or in circuit contacts. (.2 ohms.)
Tests: Check all soldered connections. Replace cathode if necessary.
Cause: Transformer shunt too close to core.
Test: Raise shunt and re-check (¼").
Cause: Insufficient secondary voltage. 1.5 V.
Test: Change secondaries or connect in series.
Cause: Transformer rotor below position of min. gap when selsyn turned down.
Test: Check—this means that part of selsyn motion merely moves rotor through "zero" position.
Cause: Selsyn reduction gear clogged.
Test: Check.
Cause: Filament generator faulty.
Tests: Check filament generator output—may be too high.
Check line voltage to see if charging belt speed too fast.

4. Unsteady or erratic target or emission current (during exposure or when circuit is tested—I_T or I_E may drift, jump, or fluctuate—tube not soft).
Cause: Filament generator faulty.
Test: Check filament generator output.
Check line voltage to see if charging belt speed is varying. Frequency—60 cycles.
Cause: Filament shorting to cup from generator vibration.
Test: Check with ohmmeter, 1000 MEGS.; replace cathode.
Cause: Poor grounding of filament.
Test: Check carefully all terminal grounds.

5. Incorrect target current (during exposure—films seem to be over-exposed consistently).
Cause: Target current shunted to ground.
Test: Check resistance B-6 to gnd. 100 MEGS.
Check target water leads for any leakage, electrical or water.

B. Soft X-ray Tube

1. Target current flickers (during exposure—not attributed to filament circuit—sometimes occurs when tube first inserted in generator).
Cause: Tube spark gaps too close, sparking across electrodes.
Test: Check by observation — re-adjust gaps.
Cause: Conducting or semi-conducting surface on glass between electrodes.
Test: Attempt to clean off—check with H.V. megohmmeter — short out section if necessary. 1000 MEGS.

Cause: Column resistor faulty. 500—100 MEGS.

Test: Short out column section—replace resistor.

Cause: Neoprene connector not fastened.

Test: Fasten connector to equipotential.

Cause: Small bursts of vapor from tube surfaces.

Tests: Check tube pressure. (See also III,C).
Put liquid air on main pumping lead trap.
Try to "run in" tube to get hard.
Lower target current to see if effect diminished.
Lower voltage to see if effect diminished.

2. Gradual build-up of soft current. (During exposure—not attributed to filament circuit —sometimes after a generator spark or at high values of target current and/or voltage.)
   Cause: Slow leak in tube developed.
   Test: Check tube pressure (See Vacuum trouble sheet).
   Cause: Insufficient pumping speed.
   Test: See I,D,2—also Vacuum trouble sheet.
   Cause: Vapors accumulating in vacuum system.
   Test: Check liquid air on main pumping lead trap. Turn off machine to allow vapors to be swept away. Reduce target current and/or voltage to see if effect diminished. Try to "run in" tube to get hard. (See also III,C).
3. Sudden burst of soft current—target current meter swinging instantly to very high value (during exposure—not attributed to filament circuit—sometimes after generator spark or after a slow build-up as in III,B,2).
   Cause: Leak developed in tube.
   Test: Check tube pressure (See Vacuum trouble sheet).
   Cause: Insufficient pumping speed.
   Test: See I,D,2 — also Vacuum trouble sheet.
   Cause: Sudden release of vapor.
   Test: Check liquid air on main pumping lead trap.
   Turn off machine. Reduce target current.
   Turn on machine and gradually nurse target current back again.
   Try to "run in" tube to get hard. (See III,C).
4. No target current—no voltage—regardless of increase in charging current (during exposure—not attributed to filament or voltmeter circuits — sometimes when machine first started up or after generator spark).
   Cause: Leak developed in tube.
   Test: Turn off filament and machine—check tube pressure (See also Vacuum trouble sheet).
   Cause: Insufficient pumping speed.
   Test: See I,D,2 — also Vacuum trouble sheet.
   Cause: Vacuum system full of vapors.
   Test: Check liquid air on main pumping lead trap.
   Allow machine to "rest" to sweep gas out of system—turn off filament and reduce charging current Variac.
   Gradually nurse back to normal again. (See III,C).
5. No target current or voltage unless charging current increased (directly when exposure button pushed—operation OK when previous exposure stopped—not attributed to filament or voltmeter circuits).
   Cause: Target current at max. value without going soft. When exposure stopped, load on charging belt decreased, thus increasing fil. gen. output and thence filament emission. When exposure started, emission momentarily too high, causing tube to go soft.
   Test: Reduce target current to value less close to max. obtainable.
   See also III,B,3 and III,B,4 above.

C. Vapors in X-ray Tube Vacuum System
1. When tube first installed (entire system being pumped).
   Cause: General contamination of system resulting from being exposed to air.
   Test: Put liquid air on main pumping lead trap and observe any improvement after several minutes' pumping.
   Check dry ice in diffusion pump trap.
2. After system has been closed up for several days (entire system being pumped).
   Cause: Accumulation of vapors in main pumping lead trap and/or diffusion pump trap.
   Test: Put special liquid air trap on fore vacuum and warm up main pumping lead trap to transfer vapors out of system. Allow to pump out for some period of time.
3. In the pump itself (main valve closed).
   (See Vacuum trouble sheet).

	OBSERVATION				CONDITIONS OF OBSERVATION				CAUSE	TEST AND/OR REMEDY
	I VOLTAGE	I CHARGE	I RESISTOR	I TARGET	VARIAC CONSTANT	VARIAC INCREASED	SELSYN CONSTANT	SELSYN INCREASED		
1	DRIFTS	STEADY	STEADY	STEADY	✓		✓		GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CIRCUIT - CHECK II A2
2	DRIFTS	STEADY	DRIFTS	STEADY	✓		✓		CORONA - DIRTY TANK AND/OR COLUMN	CLEAN UP BY SPARKING OR WIPING DOWN
3	DRIFTS	STEADY	DRIFTS	DRIFTS	✓		✓		SOFT TUBE - OUT GASSING	SEE X RAY TUBE - CHECK III B2 & III C
4	DRIFTS	DRIFTS	DRIFTS	DRIFTS	✓		✓		LINE VOLTAGE FLUCTUATION	CHECK LINE VOLTAGE - 208
5	FLICKS	STEADY	STEADY	STEADY	✓		✓		GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CIRCUIT - CHECK II A2
6	FLICKS	STEADY	FLICKS	STEADY	✓		✓		COLUMN RESISTOR FAULTY	CHECK WITH GRAD. SHORT BAR OR MEGOHMMETER
									EQUIPOTENTIAL SPARK GAP TOO CLOSE	" " " " " - READJUST.
									TUBE SPARK GAP BREAKING DOWN	" " " " " "
7	FLICKS	FLICKS	FLICKS	STEADY	✓		✓		CHARGING CURRENT CIRCUIT FAULTY	SEE CHG. CKT. - CHECK II B3
									CHARGING BELT FAULTY	CHECK WITH SHORT CKT. BAR - REPLACE
8	FLICKS	STEADY	FLICKS	FLICKS	✓		✓		SOFT TUBE OUT GASSING	SEE X RAY TUBE - CHECK III B1 & III C
9	LOW MAX.	LOW MAX.	LOW MAX.	0		✓	OFF		CHARGING CURRENT CIRCUIT FAULTY	SEE CHG. CKT. - CHECK II B4
10	LOW MAX	INC.	LOW MAX.	0		✓	OFF		CORONA - DIRTY TANK AND/OR COLUMN	SEE #2 ABOVE H.V. TERMINAL LOCKED ON?
11	LOW MAX	INC.	INC	0		✓	OFF		GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CIRCUIT - CHECK II A
12	LOW MAX	INC	LOW MAX.	INC.		✓	✓		SOFT TUBE OUT GASSING	SEE X RAY TUBE CHECK III B2 & III C
13	DROPS	STEADY	STEADY	STEADY	✓		✓		GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CKT. - CHECK II A
14	DROPS	STEADY	DROPS	DROPS	✓		✓		CORONA - DIRTY TANK AND/OR COLUMN	SEE #2 ABOVE
15	DROPS	DROPS	DROPS	DROPS	✓		✓		DROP IN LINE VOLTAGE	CHECK LINE VOLTAGE
16	0	0	0	0		✓	✓	✓		CHECK IMMEDIATELY
									CHARGING CURRENT CIRCUIT FAULTY	SEE CHG. CKT. - CHECK II B1
17	0	INC.	0	0		✓	OFF		CHARGING CURRENT CIRCUIT FAULTY	SEE CHG. CKT. - CHECK II B3
									SOFT X RAY TUBE	SEE X RAY TUBE - CHECK III B4
									GENERATOR GROUNDED	TERMINAL LOCKED ON? SHORT CKT. BAR OUT?
										SPRAY POINTS TURNED AWAY FROM BELT
18	0	INC.	INC.	0		✓	OFF		GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CKT. - CHECK II A1
19	0	INC.	0	INC.		✓	OFF		SOFT TUBE	SEE X RAY TUBE - CHECK III B3
20	STEADY (NORMAL)	HIGH	STEADY	STEADY	✓		✓		CHARGING CURRENT CIRCUIT FAULTY	SEE CHG. CKT. - CHECK II B3
									CORONA - DIRTY TANK AND/OR COLUMN	SEE #2 ABOVE
21	STEADY (NORMAL)	{HIGH LOW	HIGH LOW}	STEADY	✓		✓		COLUMN RESISTORS {LOW HIGH} IN VALUE	CHECK - REPLACE IF TOO HIGH OR LOW
									GENERATING VOLTMETER FAULTY	SEE GEN. V.M. CKT. - CHECK II A2
22	INC.	INC.	0	0		✓	OFF		RESISTOR CURRENT LEAD FAULTY	CONNECTED? - CHECK RES. - A3 TO GND.
23	STEADY	STEADY	STEADY	0	✓			✓	FILAMENT NOT EMITTING	SEE X RAY TUBE - CHECK III A1.
24	DROPS	STEADY	DROPS	0	✓			✓	BEAM NOT HITTING TARGET - {TUBE SOFT}	TRY FOCUSED BEAM. - SEE TUBE CHECK III B
25	DROPS	STEADY	DROPS	INC.	✓		✓		SOFT X RAY TUBE	SEE X RAY TUBE - CHECK III B2
26	INC.	STEADY	INC.	DROPS	✓		✓		FILAMENT SHORTING TO CUP	SEE X RAY TUBE - CHECK III A4

FIGURE 137

Generator Repair

There is a definite routine to be followed in disassembling and repairing the generator. To remove the tank, secure the main switch and use key C3 in interlock at the ladder door to release key C4 in Relay Cabinet lock. Key C4 is inserted in the tank lock to release the tank from the base. Remove the voltmeter cable and let out the air slowly, blowing out the dry ice trap in the lines. Do not open valve number 4 until pressure is down to atmospheric because the oil trap is connected to the dry ice trap by a piece of rubber hose. This will blow off if the valve is opened under pressure. Remove the water connection.

Loosen the bolts about one turn all around the tank; this causes an even pressure on all the bolts; they can then be removed by hand. Check all bolts before attempting to raise the tank. Raise the tank very slowly until the base plate is cleared. Set the tank on the deck as soon as possible. Never leave it suspended from the hoist. Before replacing the tank use a clean cloth and acetone to wipe down the inside surface.

The inspection is very important in determining the cause of sparking. Check the spark gaps for signs of sparking. Sometimes there are signs of sparking between the dome and tank; these should be noted. If there are oil spots any place in the tank, the cause should be determined to prevent burning out bearings.

The cleanliness of the tank should be noted since sparking is a function of the belt particles or the lint that may be in the tank. To remove the dome turn it to the left. Measure the resistance between each equipotential plane and ground; record.

When replacing the belt, remove the glass rod and corona bar and turn the lower spray bar away from belt.

When using pillow block wrenches lower the top pulley evenly and remove. Figure 138 shows the position of the units on the top equipotential plane; when this plate is removed, it should be set aside so that it can be worked on if needed.

The remainder of the column is built up of equipotential planes as shown in Figures 139 and 140. Figure 139 is the plane with the belt guides; these are spaced evenly up the column so that every third plane has belt spacers. Figure 140 shows plane with gradient bar only; the tool is used to space the bars.

When removing these planes, there should be a man on each side of the column. These planes are usually removed with the tube in place so that care must be taken not to jar the tube. First the resistor is removed by the man on the spring end of the resistor which is usually the lower end. The third man takes the resistors and places them in order as they are removed from the tube. The small allen set screws in the glass spacers and gradient bar are loosened about one turn so that the rods can be removed. These should be placed in separate boxes by the third man so that they are not broken. Always remove neoprene from ring before removing plane. The entire process takes about one hour. Then the lower pulley must be dropped on both sides and the belt removed.

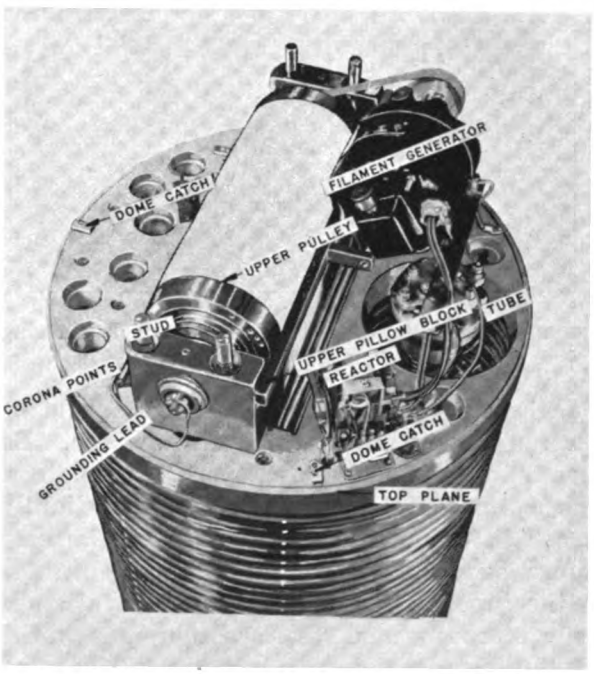


FIGURE 138

If the X-ray tube shows signs of sparking, it should be cleaned and painted with glyptal. All of the parts should be cleansed with CCl_4 before replacing. Measure the resistance of the resistors and arrange so that there are at

least 5 resistors in the top of the column below 175 megohms. Then the remainder of the resistors should be arranged so that the highest are in the bottom of the column and the lowest in the top. Do not use any resistor that is over 500 megohms. If a resistor is open, it can be repaired by using aquadag. Inspect the resistor fittings and replace all those that are worn.

When all the cleaning has been done and the column is ready to be rebuilt, open the can containing the belt, wipe surface with clean cloth dampened in CCl_4 to remove talc and insert over the pulley. Adjust the V belt drive and check centrifugal switch.

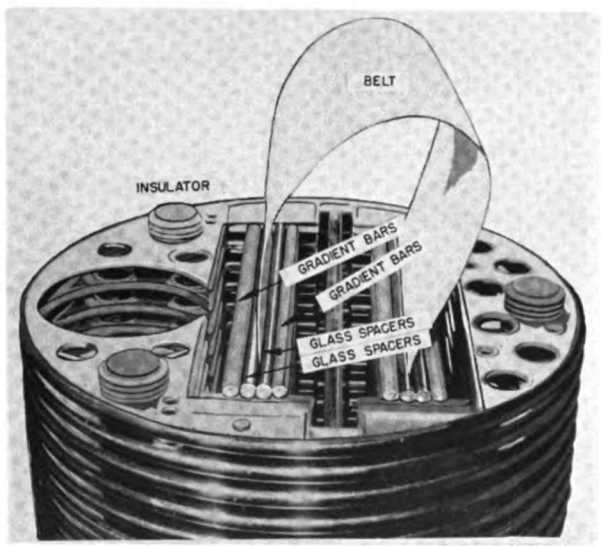


FIGURE 139. Photograph of column assembly showing a plane with belt

In building the column the rings should be lowered slowly into place over the tube. Be sure the ring is well seated over the insulators. The bottom and top insulators are slightly larger in diameter on one side; check these before starting. Place the neoprene fittings in the groove. The third man always hands the correct ring and resistor to the men on the column. Insert the gradient bars in place and tighten securely to prevent them from coming loose.

The resistors are inserted after the bars have been secured. The spring end is placed in the lower plane first; then the fitting is inserted in the top plane with screw driver. Do not use any fractured pyrex resistor shields.

The lowest resistor shield is shorter than the others.

It requires about 2 hours to build up the column. After the top plate is on the pulley in place, the belt must be tightened.

First get the belt taut; then start the motor for an instant and observe the belt. Raise the pulley block that the belt runs nearest to. This will level the pulley and place the belt in the center. Always ground the pulley when making this test. (See Figure 141). Place the corona points about 3/16 inch away from the belt. Do not adjust points while belt is running.

When making an emission test use the emission tester; directions are included with the tester. Check the vacuum before beginning.

Place the dome so that the letters A, B, C are to the left of the corresponding catches on the top plate; then rotate the dome to the right until it stops. Check to be sure the dome is secure; then measure the resistance between each equipotential plane. If resistance is over 500 megohms, short out the resistor through the spark gap. Adjust all other spark gaps with a .125" gauge. Figure 142 shows the generator completely built up.

Replace the tank as soon as possible. Start evacuating with the compressor before using the Beach Russ; then secure the compressor.

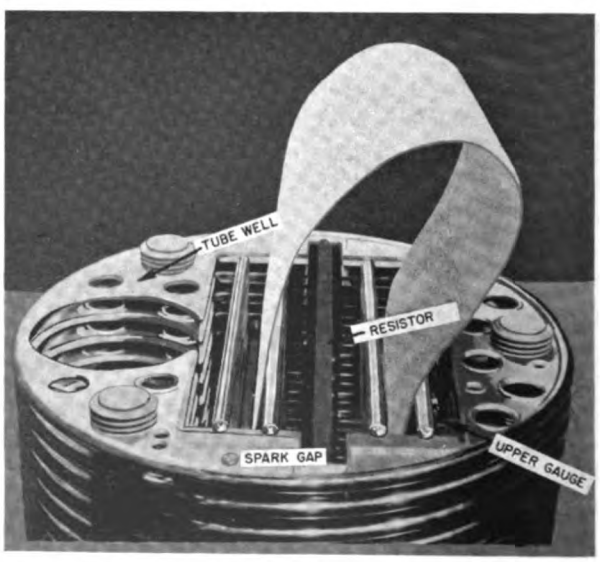


FIGURE 140. Photograph of column assembly showing a plane with gradient bars only

TABLE XXXIV

LUBRICATION CHART

	Week	*Mo.*	*2 Mo.*	*3 Mo.*	*6 Mo.*	*Year*
Beach Russ:						
Oil changed						x
Oil line checked		x				
Lens Battery:						
Charged	x					
Filled			x			
Intercooler:						
Oil				x		
Diffusion Pump:						
Radiograph		x				
Dry ice hop cleaned		x				
HyVac:						
Motors oiled		x				
Pump oil level		x				
Change oil					x	
Filament generator			x			
Generating voltmeter motor					x	
Drive motor, pulley bearing						x
Spot size camera					x	
Overhead hoist				x		
Elwell Parker Hoist:						
Battery:						
Charge	x					
Electrolyte		x				
Lubricate					x	
Yale Hoist:						
Battery:						
Charge	x					
Lubricate					x	
G. E. Chargers:						
1. Oil bearings					x	
2. Clean					x	
Circulator						
Insulation B6	x					
Distilled water changed		x				
Motor greased		x				
Compressor:						
Filter cleaned		x				
Dry silica gel		x				
Change silica gel			x			
Motor oiled		x				
Oil changed					x	

FIGURE 141. Top pulley grounded. Check for true running belt and check filament emission

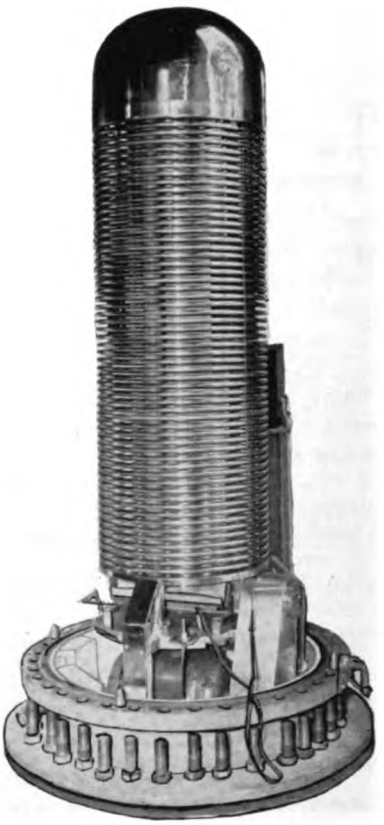


FIGURE 142. Column completely built up. Reset spray points, remove ground, replace tank

TABLE XXXV

CALIBRATION OF GENERATING VOLTMETER WITH RUBICON GALVONOMETER AND TAYLOR RESISTORS

Galv. Defl.	*Scale*	*Current*	*Chg. I*	*Voltage*
7.0 mm	X.1		0	0 Zero
66.0 mm	X.1		0	0 read.
25.0 mm	X.1	.170	.1 ma	4 KV
40.5 mm	X.1	.270	.2 ma	8 KV
57.0 mm	X.1	.385	.3 ma	12 KV
72.5 mm	X.1	.490	.4 ma	16 KV
89.2 mm	X.1	.600	.5 ma	20 KV
10.7 mm	X.01	.725	.6 ma	24 KV
12.0 mm	X.01	.825	.7 ma	28 KV
15.0 mm	X.01	1.03	.8 ma	32 KV
		sparks		
24.0 mm	X.1	.160	.1 ma	4 KV
47.0 mm	X.1	.315	.2 ma	8 KV
55.5 mm	X.1	.373	.3 ma	12 KV
70.5 mm	X.1	.475	.4 ma	16 KV
		sparks		
23.8 mm	X.1	.160	.1 ma	4 KV
39.6 mm	X.1	.265	.2 ma	8 KV
54.8 mm	X.1	.370	.3 ma	12 KV
		sparks		

Chapter 16

THE OPERATION OF THE VAN DE GRAAFF GENERATOR

The Van de Graaf Generator operates on the electrostatic principle. Therefore the only limits to the voltage that can be built up are the terminal insulation and the charging capacity of the belt.

It must be protected from excessive voltages. The controls must be carefully watched when the machine is in operation to prevent overloading the generator or the x-ray tube with too much current and voltage. The maximum advisable voltage is 2 million volts at 200 lbs. air pressure. At this voltage the tube should never carry more than 300 microamperes.

Operation

The daily check list shown in Table 36 should be followed each time the machine is started. In addition, machine performance, servicing, and any other pertinent information should be recorded each day.

When the generator is started for radiographic work the following procedure should be followed:

1. The compressor should be started to bring the pressure up to 200 P.S.I. gauge. This will reduce possibility of electrical breakdown of the insulating medium.

2. The moisture content of air should be checked by the hygrometer. This reading must be .015 grains per cu. ft., or less.

3. The vacuum pressure of the x-ray tube must be at least 1.0×10^{-5} mm. Hg., or better; fore vac should be .01 mm. hg. *Do not operate above these limits. Operation may burn out filament.*

4. The cooling coil on the mercury diffusion pump should be slightly below room temperature while the lower section of the pump should be slightly above room temperature. This test can be made by feeling with the hand.

5. The vapor trap below the diffusion pump should be immersed in liquid air to improve the pumping speed and trap out the gases. A mixture of dry ice (CO_2 and alcohol) can be used in emergencies.

6. The diffusion pump trap should be at least one-half filled with dry ice at all times.

7. The main switch can now be turned on. This will:

a. Start water through coil in tank.

b. Pump distilled water to lens coil.

c. Pump distilled water through water jacket about the gold x-ray target. The gauge on curculator should read 30 P.S.I. and the level should be ½ full.

d. Start generating voltmeter motor.

e. Light the filaments of 6H6 tubes in voltmeter circuit.

f. Energize the selsyns.

g. Power to all electrical interlocks.

h. Power to the magnetic lens switch.

i. Power to the motor switch.

8. Key C–1 is used to trip the time delay

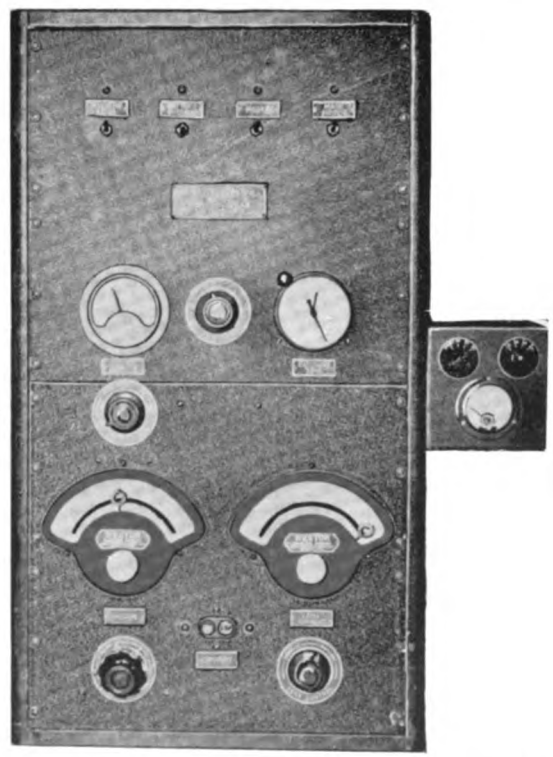


FIGURE 143. Photograph of the control panel of the Van de Graaff 2 M.E.V. electrostatic x-ray generator

TABLE XXXVI

DAILY CHECK LIST

Gen. Timeter: ..... Date: .....

Tube Timeter: ..... Time: .....

CONDITION	DATA TAKEN BY
High Vacuum: ..... Fore Vacuum:	.....
Diffusion Pump Dry Ice ☐	.....
Main Trap Temp. - Room ☐ CO_2 ☐ Liq. Air ☐	.....
HyVac Protective - OK ☐ If tripped, note time: ..... Reset ☐	.....
Tank Pressure: ..... Pumped up? ☐	.....
Dew Point:	.....
Circulation: Time, from ..... to	.....
Date Silica Gel dried last	.....
Battery Condition:	.....
At 2.0 MV, no load: I_c	.....
I_r	.....
Max. I_t obtainable:	.....
At 2.0 MV, under load: I_c	.....
I_r	.....
I_t	.....
Remarks on Performance:	
Generator Use: (Book ..... Page .....)	.....
Securing Time: ..... Tank Pressure:	.....
High Vacuum: ..... Fore Vacuum:	.....
Diffusion Pump Dry Ice ☐	.....
Batteries on Charger ☐	.....
Remarks Regarding Securing:	.....
.....	

Any observations, changes, maintenance to be recorded on following pages.

relay from the remote interlock in the exposure room, and returned to lock the control room door within 30 seconds which energizes the circuits used for starting exposure. The horn warns personnel to leave the area. The interlock circuit is shown in Figure 148. When key C–1 is turned in interlock, horn is energized for 30 seconds. When control room door is locked:

a. Horn is stopped.
b. Green light comes on.
c. Puts power on exposure button.

9. Turning on motor switch:

a. Lights filaments in high voltage transformer.
b. Ungrounds high voltage cable.
c. Starts charging belt.
d. Starts filament generator.

10. The green light is a signal to start the exposure by pressing the *exposure button.*

a. Starts timer on control panel.
b. Starts tube timer.
c. Puts power on variac.

The control panel is shown in Figure 135. This contains all the controls to the generator. The generator terminal voltage is adjusted by the variac transformer knob (marked VOLTAGE CONTROL) at the lower left hand corner of the control panel. The terminal voltage is indicated on the calibrated microammeter just above it (marked VOLTAGE).

This variac provides a means for controlling the amount of charge "sprayed" on the insulating belt by direct control of the input to the 75 KV power supply feeding the corona "spray" points. For 2.0 M.E.V. the variac is adjusted so that the meter needle is opposite the red indicator.

With the voltage setting made the desired target current may be obtained by turning clockwise the selsyn motor knob located just above the voltage meter (marked CURRENT CONTROL). The receiver selsyn motor controls the vertical motion of a glass rod in the generator column; this motion in turn is utilized to move the rotor of a transformer supplying current to the filament of the x-ray tube. The microammeter just above the selsyn knob indicates TARGET CURRENT.

699810—46—10

This reading is multiplied by the range switch setting to get the true target current.

Loading the generator by increasing the target current will cause a drop in the terminal voltage. This is because a portion of the charging current that was used to maintain 2.0 MV without a load (except for resistor current and corona loss), is now being directed down the x-ray tube. Thus in order to obtain this additional generator load and still maintain 2.0 MV, it will be necessary to supply this current by turning up the *voltage control* knob, thereby increasing the belt "spray" current.

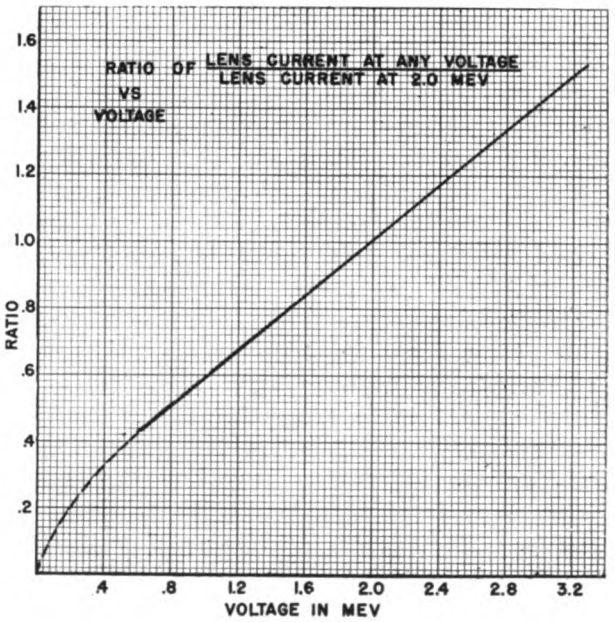


FIGURE 144

The *magnetic lens* switch may now be turned on and the desired lens current adjusted with the rheostat knob (marked LENS CONTROL) at the lower right hand corner of the control panel. The ammeter (marked LENS CURRENT) just above this knob indicates magnet current. For 2.0 MV the current is set to the red indicator. For any other voltage the setting can be obtained from the chart, Figure 144.

After the generator is beamed the exposure may be started and stopped by pressing "start" and "stop" button. The key system must be energized each time the door is opened so that the horn sounds and the green light comes on.

Securing

Before the switches of the control panel are secured, the voltage control and target control knobs should be turned to zero. This prevents any possibility of putting voltage and current on the generator by pressing the start button switch. This might burn out the filament and break down the insulation in the column.

The magnetic lens battery may be charged by turning on *the battery charger* switch on the control panel.

McLeod Gauge

The McLeod gauge is a vacuum gauge based on the principle of Boyles' Law, which states that $P_1V_1 = P_2V_2$, meaning that the pressure times the volume is equal to the second pressure times the second volume if the temperature remains constant. Since the pressures in the vacuum system are very low, the second volume must be small. This is done by using a small closed capillary. The mercury in the pot on the right is a means of applying a definite pressure on the volumes of air in the two bulbs. This pot is raised manually.

The mercury rising in the tubes traps off the air in the bulbs from the rest of the system. Then, if the mercury is brought up to the level marked *UP*, so that the top of the meniscus is level with this line, the pressure may be read opposite the top of the mercury level in the capillary. The fore vac reads between 1.0 and .001 millimeters of mercury. The High Vacuum scale is calibrated between 2×10^{-2} to 1×10^{-5} millimeters of mercury. the original volume (V) was the sum of the bulb plus the closed capillary. The final volume was the upper end (above the mercury) of the closed capillary. "H" is the difference in the height of the two mercury columns; therefore $P_1 = \frac{V_2}{V_1} H$ mm. of Hg. (Actually $P_1 = \frac{V_2(P_1+H)}{V_1}$ but P_1 is so small in comparison to H that it may be disregarded.)

There are two McLeod gauges, one on the fore vac system and one on the high vacuum system. The calibration is different for each system; therefore two settings must be made and readings taken one on each capillary. When opening the vacuum system, remove the mercury pot and hold it in such a position that the mercury is below the "Y" allowing the fore vac system to be opened to the high vacuum system. If trouble is suspected in the McLeod gauge, the vacuum schedule may be consulted

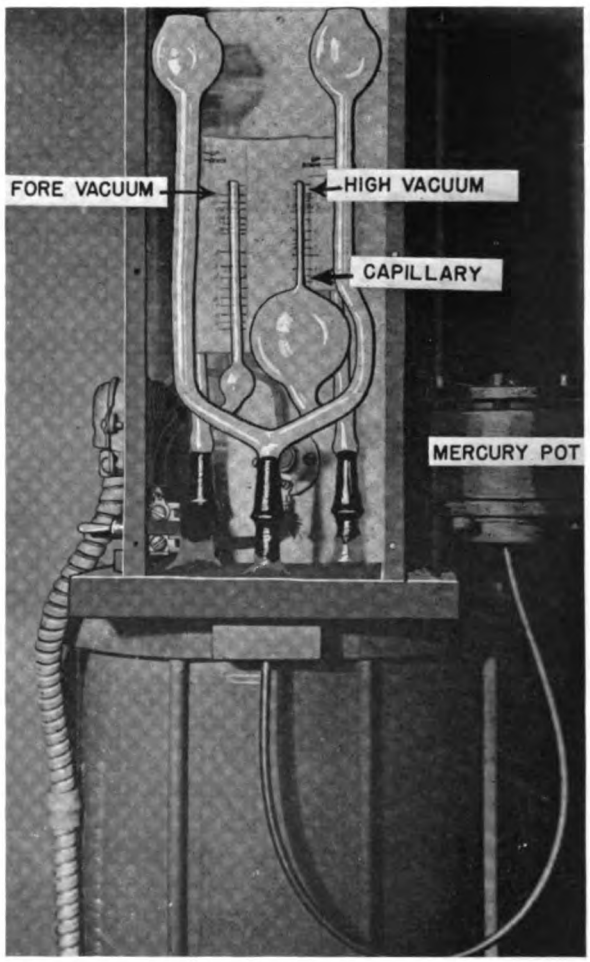


FIGURE 145. Photograph of the McLeod Gauge used on vacuum system of the Van de Graaff x-ray generator

Hygrometer

Attached to the compressor system at the air inlet to the tank is a dew-point hygrometer apparatus which serves to measure the moisture content of the tank air. This consists of a silvered mirror at the base of a cup in the atmosphere of the tank. This mirror, when sufficiently cooled, will condense moisture from the air flowing by. To be sure to get a good sample of air, the large valve, No. 6, should be wide open and small one, No. 3, cracked enough so

a small stream of air goes through while readings are being made. A small amount of alcohol is poured into the cup, and just enough chopped dry ice is added to boil the alcohol. The mixture is stirred gently with a low temperature thermometer while the mirror is observed through the window. The temperature of this mirror is thus slowly lowered until it just clouds over. The thermometer reading when this occurs is the temperature of the dew-point of the tank air. The corresponding relative humidity and absolute water content of this sample of air can be obtained from the dew-point chart. (See Figure 146.) It is best after getting one reading to soak the alcohol out of the cup, warm the mirror to room temperature, and repeat the measurement to get a check reading. For reliable generator operation, the dew-point should measure –50°C. or lower. For air temperature of –70°F., the corresponding value of relative humidity is .2% with a water content of .015 grains per cubic foot.

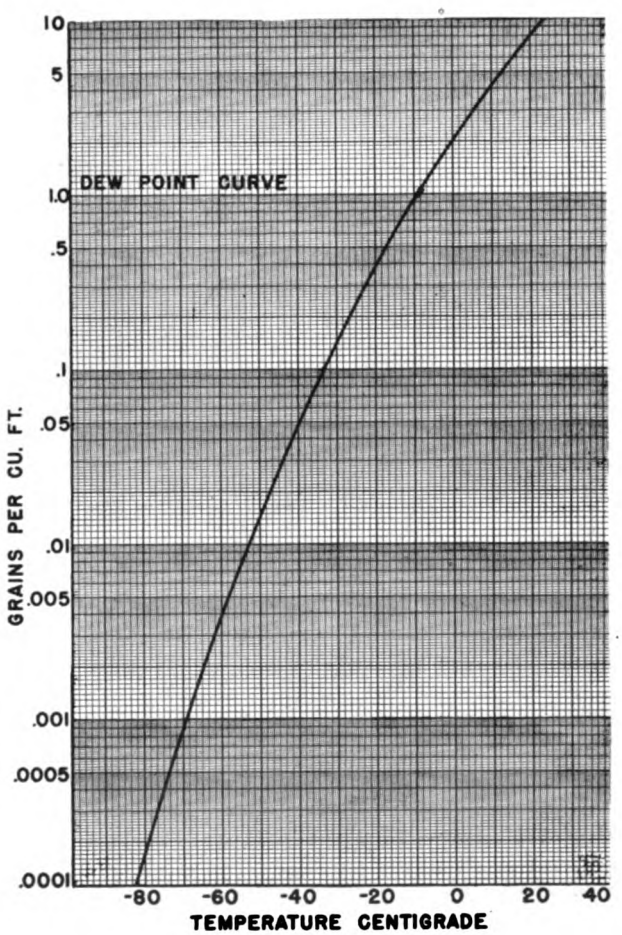


FIGURE 146

Trouble Shooting

When the generator is operating normally, *the charging current should be equal to the resistor current plus the tube current;* loss should not exceed 50 microamperes for full load. This balance is checked before each day's operation. The resistor current is equal to the voltage divided by the resistance in the resistor column. Therefore if the resistance is 14,300 $\times 10^6$ ohms, the resistor current should be 140 ua. The tube current can be checked by opening and closing the magnetic lens switch. If the current changes, then the tube is conducting soft current, part of which is not striking the target. The vacuum system should be checked according to the schedule.

If the generator is sparking, the pressure should be checked to be sure it is up to 200 P.S.I. If the pressure is below 190 P.S.I., start the compressor and pump up. This type of trouble is indicated by the dome sparking across to the tank. This is a very loud spark.

The belt may be too wet for operation. In this case the sparking is a function of the charging current and not a function of the voltage. This is checked by lowering the voltage and putting the same charging current on the belt. If the sparking rate is the same, then the belt should be re-dried by circulating the air. By looking in the port, a glow or sparking on the up side of the belt, if present, may be seen.

If the tube pressure is poor, the machine will spark badly; this is indicated by the tube going "soft." The pressure should be checked immediately and the motor stopped. If the vacuum is good there may be vapor in the system; then the fore vac liquid air trap should be placed in the line.

Sparking may be caused by irregular potential gradients near the top of the column. This is indicated by high resistance or an open resistor in the columns. Sometimes this is indicated by the resistor current reading low, or no current at all. The resistors should be changed so that the lowest are in the top and progress in ascending order to the bottom.

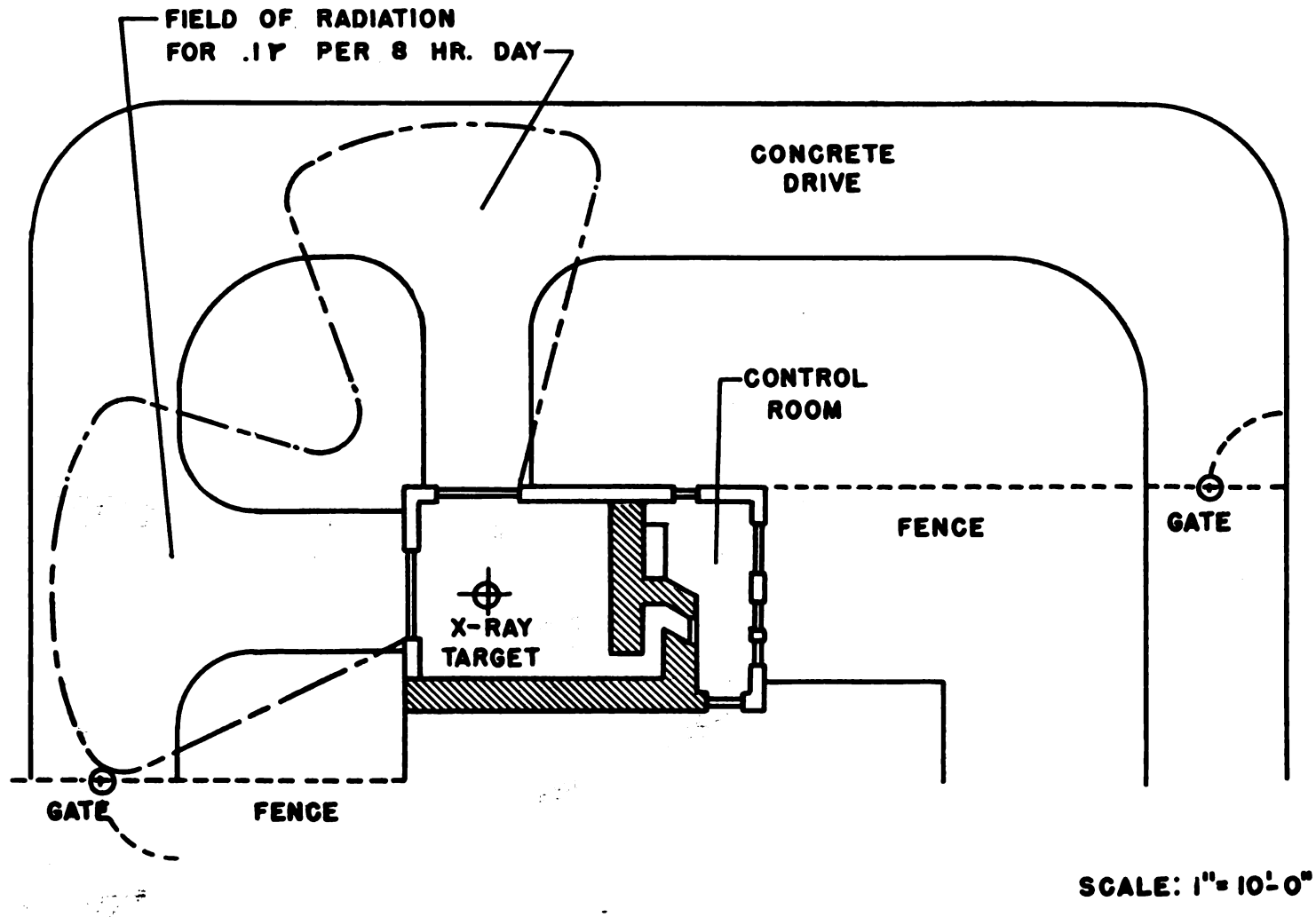

FIELD OF RADIATION
FOR .1 P PER 8 HR. DAY
CONCRETE
DRIVE
CONTROL
ROOM
FENCE
GATE
X-RAY
TARGET
GATE
FENCE
SCALE: 1"= 10'-0"

FIGURE 147

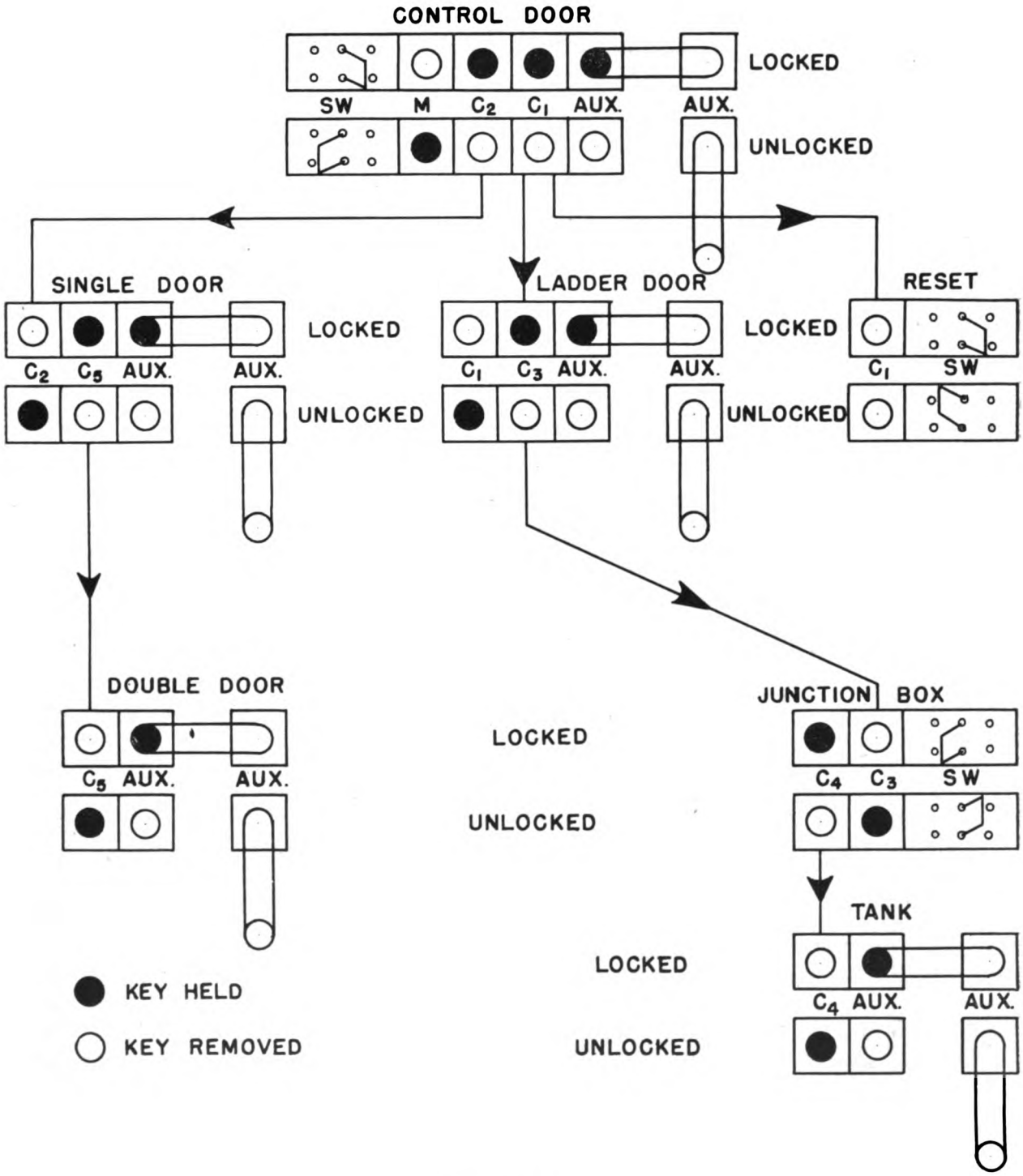

CONTROL DOOR
SW
M
C2
C1
AUX.
AUX.
LOCKED
UNLOCKED
SINGLE DOOR
C2
C5
AUX.
AUX.
LOCKED
UNLOCKED
LADDER DOOR
C1
C3
AUX.
AUX.
LOCKED
UNLOCKED
RESET
C1
SW
DOUBLE DOOR
C5
AUX.
AUX.
LOCKED
UNLOCKED
JUNCTION BOX
C4
C3
SW
TANK
C4
AUX.
AUX.
LOCKED
UNLOCKED
KEY HELD
KEY REMOVED

FIGURE 148

If the column is dirty due to belt material in the machine it will spark. The tank should be removed to clean column.

If the generator is operated at too high a voltage, sparking or insulation breakdown will occur. If the generator is to be operated above normal voltage, it should be conditioned and handled very carefully.

Difficulties are sometimes indicated by noises from the microphone. The belt may run too far to one side of the pulley; in this case there will be a scraping noise. The motor should be stopped and pulley adjusted.

If a glass rod breaks, the fragment will probably cause a clicking noise. This condition should be corrected at once by taking out all the rods that are broken or fractured.

If the belt breaks, then there will be a very loud noise for an instant. The break may be verified through the port.

If the power goes off, the routine indicated in the alarm system schedule should be followed.

Safety Devices

Since the exposure to radiation is injurious to personnel there are several safety measures that must be observed.

Figure 147 shows the field of scattered radiation about the building that is dangerous to personnel. Inside the area shown is above .1γ per eight-hour day.

The Interlocks (see Figure 148) are to prevent the opening of the doors that lead to the areas of radiation. These locks should not be bypassed by duplicate keys making it possible to enter these areas without the operator being cognizant. If the locks are operated properly the only door than can be opened is the control room door. Opening this door puts current through relay 6–1,2, closes relay 4–1,2, blows the warning horn, and breaks the charging circuit.

Each time the machine is started the horn circuit is energized. This horn warns all personnel in the area to leave immediately. The

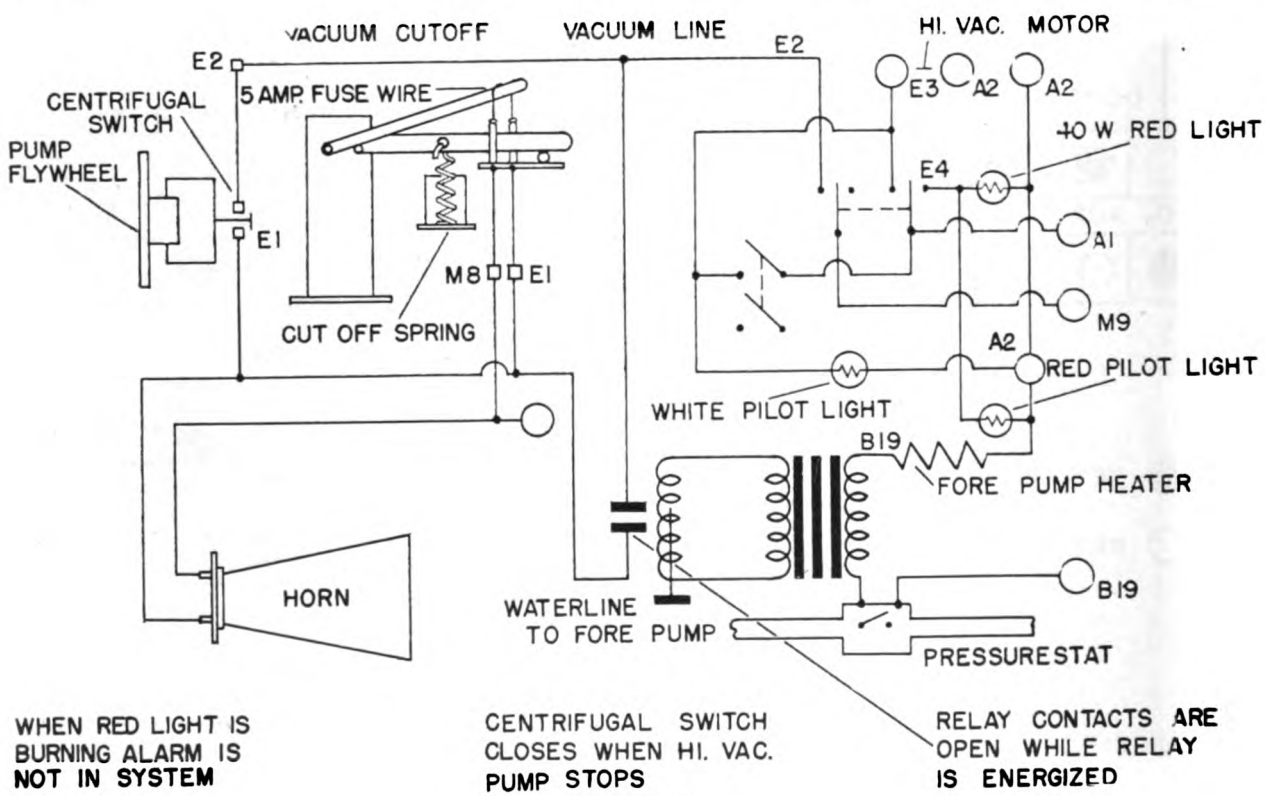


FIGURE 149

operator in charge is responsible for the observance of these safety rules.

Since there are no exposed high tension leads, the electrical protection is not such a problem; however, when the tank is removed, the high voltage lead should be grounded. This is done by the transformer, but it is well to check the lead each time. When operating the generator without the tank on for emission and belt test, the top equipotential plane should be grounded to the base. The Interlock in the tank and Relay Cabinet is another protection against the operation of the generator from the control panel without the knowledge of personnel on the second deck.

Operation of Vacuum Protection Alarm System

This system should sound a warning when the tube is in danger of losing its vacuum. (See diagram shown in Figure 149.)

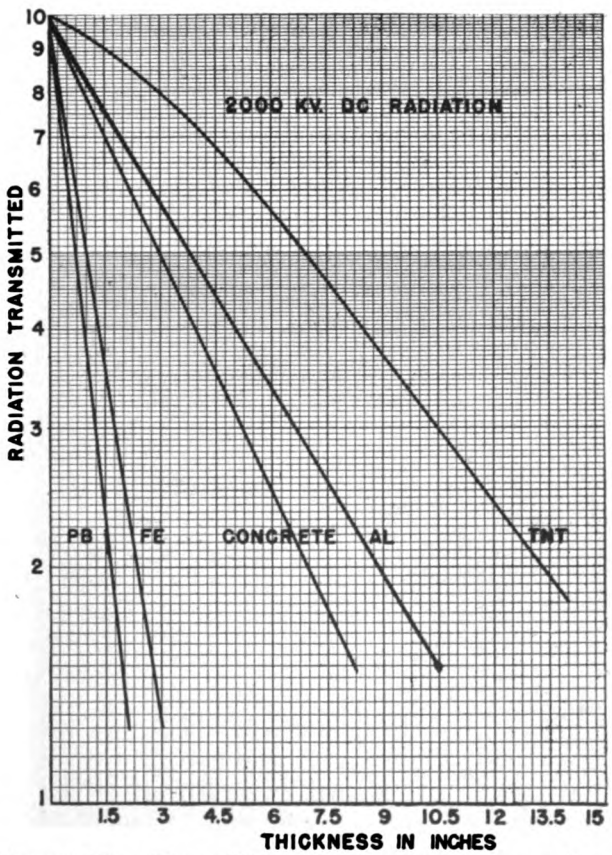


FIGURE 150. Two million volts absorption curves. Radiation transmitted is shown in units of 10 per cent

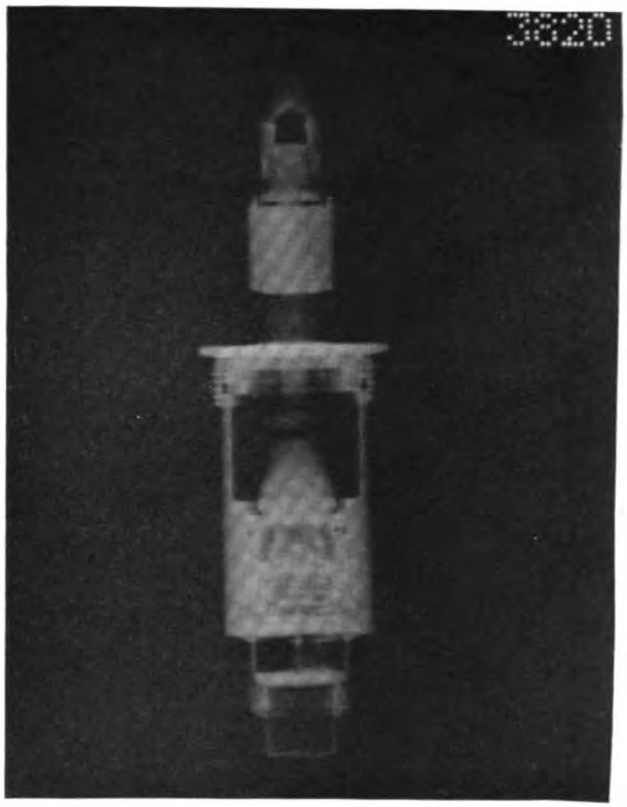


FIGURE 151. Fuze radiograph made at .5 M.E.V.

The alarm is a 32 volt D. C. horn that will blow when (1) water pressure drops below normal, (2) belt on pump breaks, or (3) power fails on the pumping systems.

The pumping system consists of two pumps: (1) HyVac Pump, (2) mercury diffusion pump. Both are powered by 110 volt A.C.

The HyVac pump is driven by a 110 volt A.C. motor. A belt from the shaft or pulley of this motor is connected to the fly wheel of the pump. This fly wheel on the pump has a centrifugal switch on it which is open as long as the flywheel is revolving.

The mercury diffusion pump operates as long as there is power to the heater. In order for the heater to operate, water must be flowing to the heater to cool it. The input to the heater must first go through a pressurestat. Normal water pressure must be flowing through the pressurestat to close the pressurestat switch and operate the heater.

As long as the white pilot light is burning, the alarm is in the circuit and failure of any-

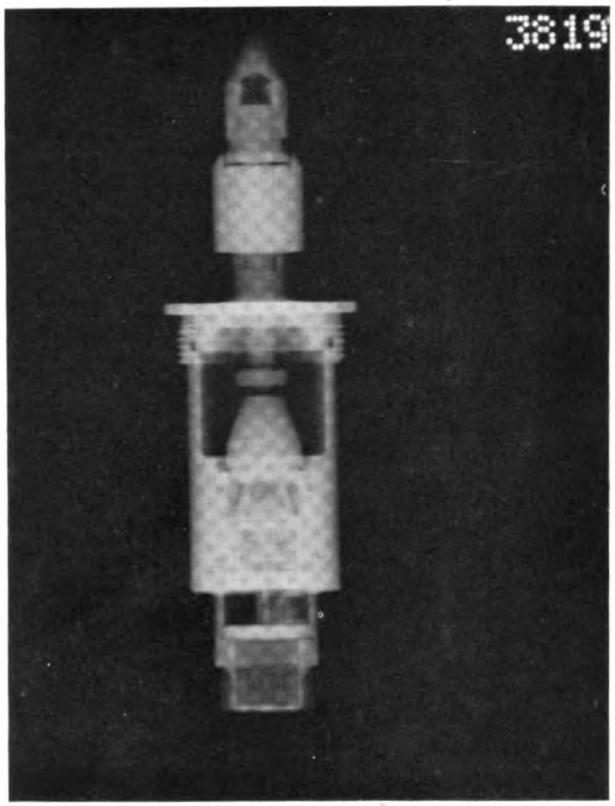


FIGURE 152. Fuze radiograph made at 1.0 M.E.V.

thing mentioned above will blow the horn. When red lights are burning, the alarm is not in the system and horn cannot blow. The pumping system will still operate, meaning when a change is made from station power to laboratory power, red lights must be burning.

If the power or the belt fails on the HyVac pump (E2) from switch feeds 32 volt positive D.C. current to the centrifugal switch on pump fly wheel. This switch is now closed and passes current into horn returning on (M8) completing the circuit and blowing the horn. This also puts the 5 ampere fuse wire directly across M8 and M9 and burns it in two. When the wire burns, it releases the arm held by it allowing the spring to compress pulling another arm down on vacuum line and pinching the tube.

If power or water fails on mercury pump, the transformer is de-energized, de-energizing the relay and closing the contacts. E2 from switch feeds 32 volts through relay contacts to horn returning on M8 completing the circuit. This action also puts 5 amp fuse wire across M8 and M9 (32 volts) and burns it in two, thus pinching off tube. The horn will stop blowing only when the D.P.D.T. switch is thrown and red lights are burning. Replace fuse wire and when trouble is over, switch on white lights.

Radiography

The Van de Graaff generator, as a radiographic tool, has several advantages over other generators. The most important advantage is a D.C. voltage source across the x-ray tube which yields a higher effective voltage.

Absorption Coefficients at 2 MEV, C.P.

	TNT	Al	Concrete	Iron	Lead
u =	.0463	.072	.090	.274	.457

These values were obtained from the absorption curves shown in Figure 150. The percentage of 2 M.E.V., C.P., transmission through lead, iron, concrete, aluminum, and TNT is plotted against thickness in inches.

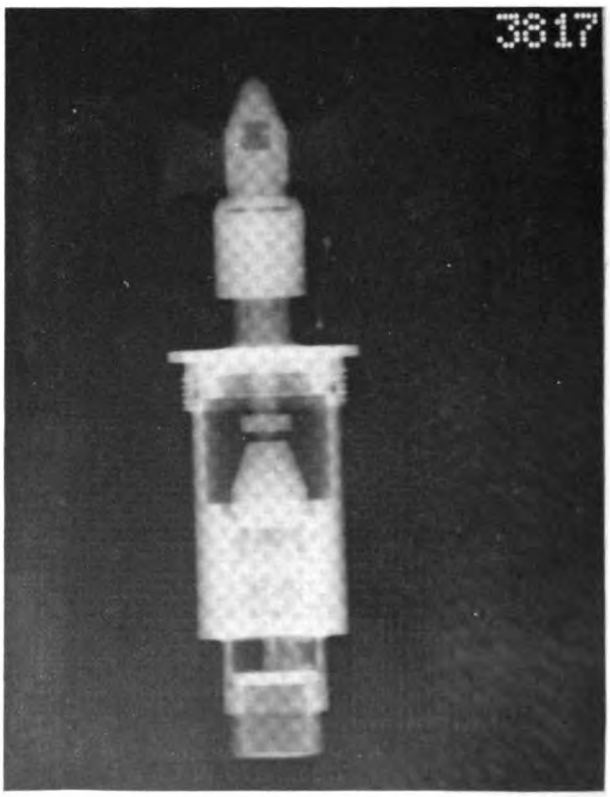


FIGURE 153. Fuze radiograph made at 2 M.E.V.

Contrast, Latitude and Exposure Time

The variation of contrast and latitude with voltage is indicated in Figures 151, 152, 153 and 154. The higher voltage allows more latitude and produces less scattered radiation and undercutting. The exposure time is greatly decreased by increasing the voltage as shown in Figure 155. These are the voltages and exposure times of the fuze radiographs mentioned above. The 1.5 M.E.V. radiograph was not printed because the exposure time was excessive and the density of the film too great.

Film Exposure Factors

To find the exposure time for other films when the exposure time for A film is known, multiply by the following factors:

Type Film	*Factor*
M	4.0
A	1.0
F Pb	.75
K	.20
F 245	1/30 or .033

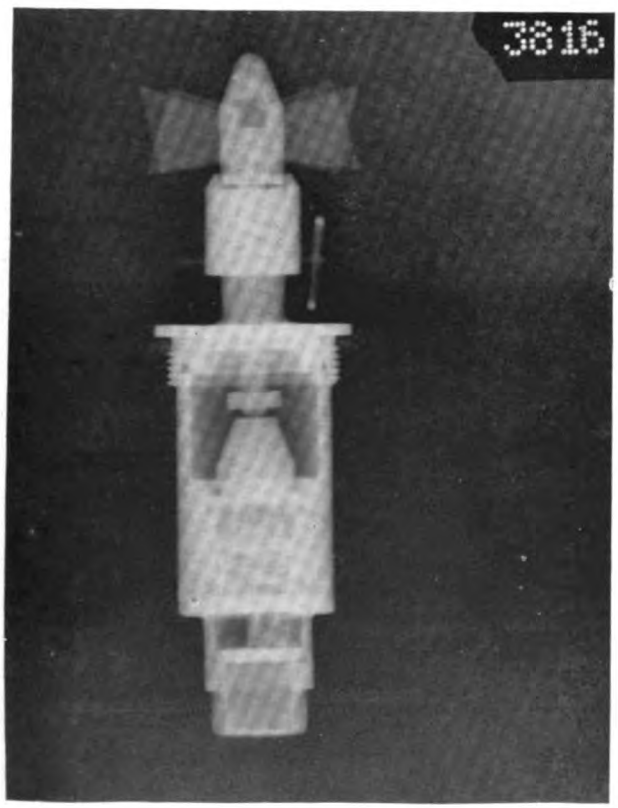


FIGURE 154. Fuze radiograph made at 2.5 M.E.V.

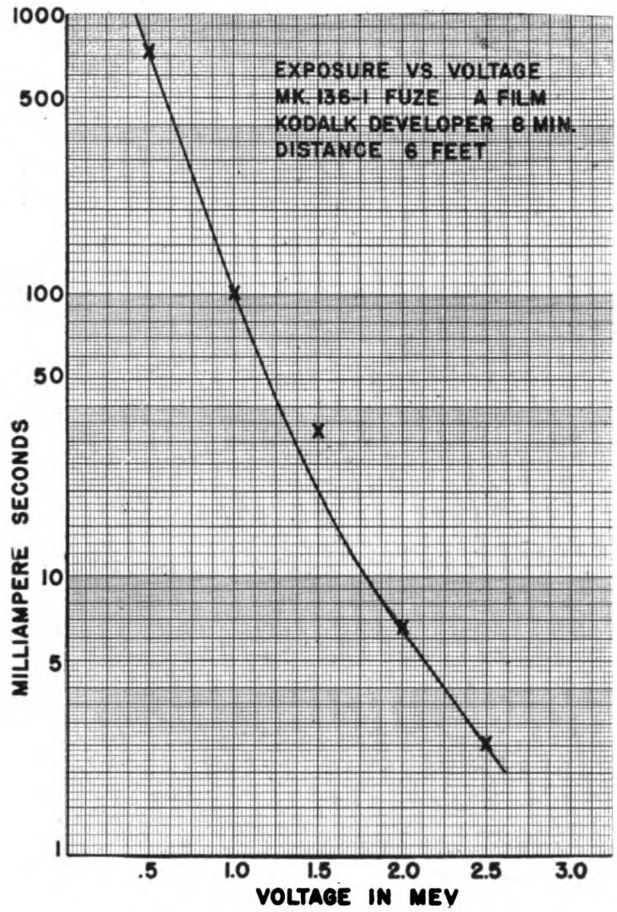


FIGURE 155

Focal Spot Size

The small spot .010 in. to .020 in. improves definition and makes it possible to make projections.

Figure 156 (center) shows the effect of the focal spot size on a projection made by placing a fuze at 6 ft. and the film at 12 ft. producing an image twice the size of the object. Number 1 (left) is a contact made by placing the object on film. Number 3 (right) is the enlargement made with unfocused beam. It can be seen that it is very important to have magnetic lens set correctly.

Intensity

The variable current allows the exposure to be adjusted to the desired time. This is convenient when exposure times are extremely small.

The gold x-ray target increases the efficiency

FIGURE 156

of the x-ray production and filters out the longer wave length radiation giving essentially high voltage radiation only. The radiation output vs. inches of steel is shown in Figure 157. This output is 900R/hour at 6 ft. at 2 M.E.V., and 300 ua.

Sensitivity

Sensitivity as applied to radiography is the smallest percent of change in thickness of material that can be detected on a radiograph. It is extremely difficult to obtain accurate sensitivity curves; however, enough work has been done to state (1) that at 3 inches of steel sensitivity is improved by the increasing of lead filter thickness up to .80 inch; (2) that sensitivity improves with increase in thickness at least to 10 inches of steel.

It is also dependent on scatter and therefore varies with object material, size and shape.

Using Kodalk developer (8 min. –68°F.) the following sensitivities were obtained through 3 inches of steel:

Type Eastman Film	*Sensitivity*
M (lead screens)	.4%
A (lead screens)	.6%
F (lead screens)	1.4%
K (lead screens)	.8%
F (No. 245 screens)	1.6%

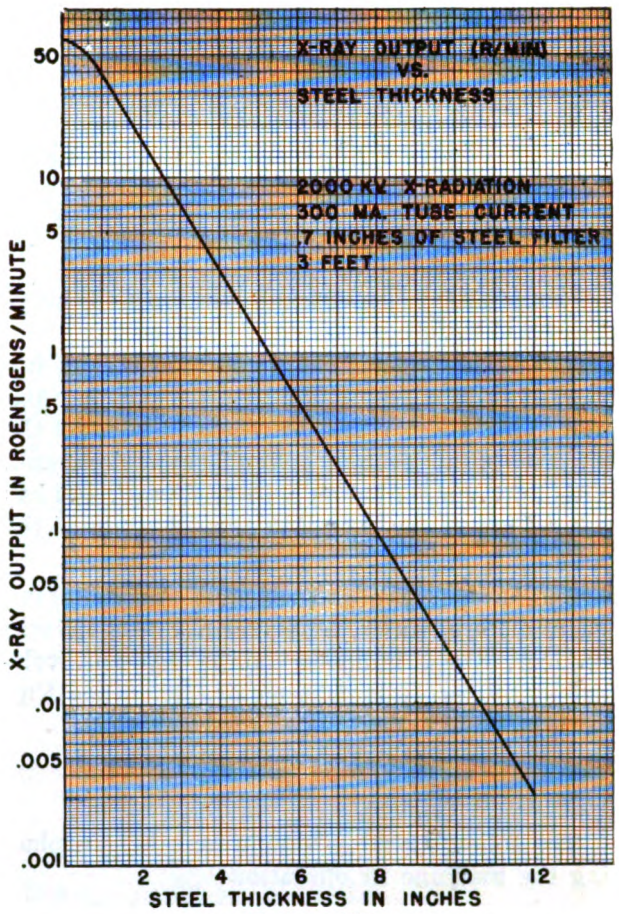


FIGURE 157

Chapter 17

THE OPERATION OF THE GENERAL ELECTRIC OX-400 X-RAY GENERATOR

The General Electric OX 400 is made up of two main units:

1. The tube head which contains the oil immersed tube, high tension transformer and filament transformer and to which is secured the oil circulating system and oil expansion tank. This unit is mounted on a 4 wheel truck and has a hand crank for changing the elevation of the tube.

2. The control stand contains the switching gear, meters, timer, auto transformer, inverse reducer, fuses, indicator lamps, filament voltage stabilizer, tube time meter, etc. (See Figure 93 for picture of machine.)

Operation of Unit

The following steps should be taken in placing the machine in operation:

1. Check shutter indicator lights to be sure shutter is closed. If it is open, check timer switch located beneath the timer.

2. Turn filament control rheostat until it points between 45 and 50 for 5 M.A. operation.

3. Depress the "On" line switch button. It will be necessary to hold the button in for a few seconds until the oil circulating pump has built up enough pressure to close the low pressure trip switch contact through the already closed contact of the high pressure trip switch. The line contactor is then held in by its interlock.

4. Set the auto-transformer tap selector to the proper point to produce the desired KV at the tube (see Table XXXVII). The setting should be higher than the desired voltage by the amount of the voltage drop due to the regulation of the power line and inverse reducer.

5. Make sure the rheostat control is set at button #1. This insures that all the resistance will be in the primary circuit of the high voltage transformer, thus preventing any undue voltage surges in the high voltage circuit.

6. Depress the "On" x-ray switch button to close the magnetic switch which completes the circuit to the primary of the high tension transformer. The x-ray contactor closing circuit is fed through a switch which must be closed by the rheostat control being set on button #1 to insure that all the resistance is in the circuit on starting.

7. Simultaneously adjust the filament control to give the proper tube millamperage and slowly cut out the rheostat. The rheostat should be cut out at such a rate that it will take one minute to completely cut it out. A greater part of this time should be taken up after the kilovoltage has reached ¾ of its final value. This time is especially important when the machine is cold.

8. Set timer to the desired length of exposure up to 20 minutes by the knob extending through the dial face.

9. Open the radiation shutter by depressing the shutter "On" button. When the shutter is completely open, the red (shutter open) indicator light will come on. When the exposure time is up the timer acts to close the shutter. The shutter on closing completes the circuit through a set of contacts to the green (shutter closed) indicator light.

10. De-energize the x-ray circuit by depressing the x-ray "Off" button. This breaks the x-ray contactor hold-in circuit.

11. De-energize the control stand by depressing the line "Off" push botton. The "Off" button breaks the hold in circuit of the line contactor. The line switch should not be cut out until at least one minute after the x-ray circuit has been de-energized to allow the oil circulator to cool the tube anode.

Viscosity Regulator

The unit is also equipped with a circulating oil preheater which is a thermostatically controlled electric heater in the suction line of the oil circulating pump. The heater is energized by a tumbler switch on the control panel and is paralleled with a red indicator light. If the tube head temperature is very low the preheater should be turned on before energizing the control stand. The control stand may be turned on after the red indicator light goes out, indicating that the heater has cut off and the oil is warm enough.

Notes on Operation

Always make sure the auto-transformer tap selector is centered on its contacts.

Never change the setting of the auto-transformer tap selector while the x-ray circuit is energized.

If the tap selector is not centered or is changed during the exposure, excessive overloading of a portion of the contacts or inductive arcing will cause burning of the contacts.

Focal Film Distance

In radiography of anything up to the equivalent of 1 inch of steel it has been found that by using a focal-film distance of 12 feet the results were much better and the exposure times not excessive. By using this long focal-film distance it is found that the fuzziness of line caused by the large focal spot is eliminated and the distortion, especially in large objects, is decreased considerably.

Tube Current

In order to obtain the highest radiation output the machine is usually operated at maximum allowable tube current. Following is a calibration chart showing tube Kv.P, with corresponding voltmeter readings and allowable tube currents.

TABLE XXXVII

	Tube Kv.P	*Voltmeter Readings Under Load*
	100	55.5
Not over	110	60.5
	120	66
2 Ma.	130	71.5
	140	77
	150	82.5
	160	88
	170	93.5
Not over	180	99
	190	104.5
	200	110
3 Ma.	210	116
	220	121
	230	127
	240	132
	250	138
	260	143
	270	149
Not over	280	154
	290	160
	300	165
	310	171
4 Ma.	320	177
	330	182
	340	188
	350	193
Not over	360	199
	370	204
5 Ma.	380	210
	390	215
	400	220

Focal Spot Size

The projected focal spot is 4.5 millimeters square. In Chapter 11 there are two reproductions (Figures 105 and 106) which demonstrate the fuzziness of lines due to focal spot size in the 3 ft. radiograph and the absence of fuzziness in the 12 ft. radiograph. These radiographs also demonstrate the large amount of distortion in the 3 ft. radiograph and a very small amount in the 12 ft. radiograph.

Radiation Output

The radiation output at 400 Kv.P, 5 Ma., 12 ft. from the focal spot is 90 roentgen units per hour. The radiation output at any other distance may be approximated by the use of the Inverse Square Law.

Absorption Coefficients.

Following is a table showing the measured absorption coefficients and effective Kv. of the machine:

TABLE XXXVIII

Kv. P	*MM. Cu. Filter*	*Material*	*Linear u*	*Mass u/p*	*Eff. Wave-length*	*Eff. Kv.*	*Kv.P / 1.3 x Kv. Eff.*
400	4	Pb	10.5	.925	.0485	258	336
400	4	Cu	1.325	.1485	.048	260	338
400	4	Fe	1.025	.135	.048	260	338
400	4	Al	.291	.112	.048	260	338

Technique Charts

Technique charts for steel and aluminum at 400 Kv.P are shown in Figure 92.

The following are half-value layers at 400 Kv.P if this system of determining exposures is to be used. These measurements are without filtration.

Aluminum 1.5"	Copper .10"
Steel .25"	Lead .016"

Wiring Diagram

A simplified wiring diagram showing only the main x-ray circuits is shown in Figure 158. There are a large number of control and protective circuits but it is felt that they can be better followed on the large complete blue print. To prevent a large inverse peak voltage, that is, a higher than normal voltage on the half cycle that the x-ray tube is not conducting, an inverse peak reducer is used. This consists of a resistance and "tungar" tube in parallel in the primary circuit of the high voltage transformer. During that half cycle that the x-ray tube is conducting, the "tungar" tube is also firing, and so, carries most of the primary current but in the other half cycle the "tungar" tube does not fire so the primary magnetizing current is fed through the resistance alone. Due to the IR drop in the resistance, the voltage across the primary winding of the high tension transformer is reduced with a consequent reduction of the secondary voltage. The unit is also equipped with a Raytheon voltage stabilizer in the x-ray tube filament circuit to maintain a steady filament current in spite of flucatuating value of line voltage.

Troubles and Remedies

Following is a list of some of the more frequent troubles and remedies:

a. Line contactor will not hold in or chatters when line switch "On" button is depressed. This usually happens in cold weather when the oil thickens and its cause is the opening of the high pressure oil trip switch. The remedy is to preheat the circulating oil by means of the viscosity regulator or heater.

b. Inverse reducer resistance heats up causing warm spot on panel front. This is usually caused by poor contacts somewhere at the "tungar" tube so that it is not carrying the load current properly. Remedy, screw tube firmly in socket and make sure of good contact on top plate contact. Renew tube if "burned out".

c. Timer does not close shutter. This quite often is caused by the timer switch being in the wrong position. Remedy, turn timer switch on.

d. Green shutter closed light does not come on. Occasionally this happens and is usually caused by the shutter sticking mechanically and so does not close the contacts. The remedy is to remove the shutter cover and free shutter.

e. The x-ray contactor does not pull in when the x-ray "On" button is depressed. This in practically every case is caused by the rheostat not being at contact #1 to hold the protective switch closed. The remedy is to move the rheostat control to contact #1.

Safety Devices

These features are divided into two classes (1) electrical and (2) radiation.

(1) Following is a list of the electrical safety devices and features:

a. Shock proof head. The high voltage equipment is mounted within the tube head which is at ground potential.

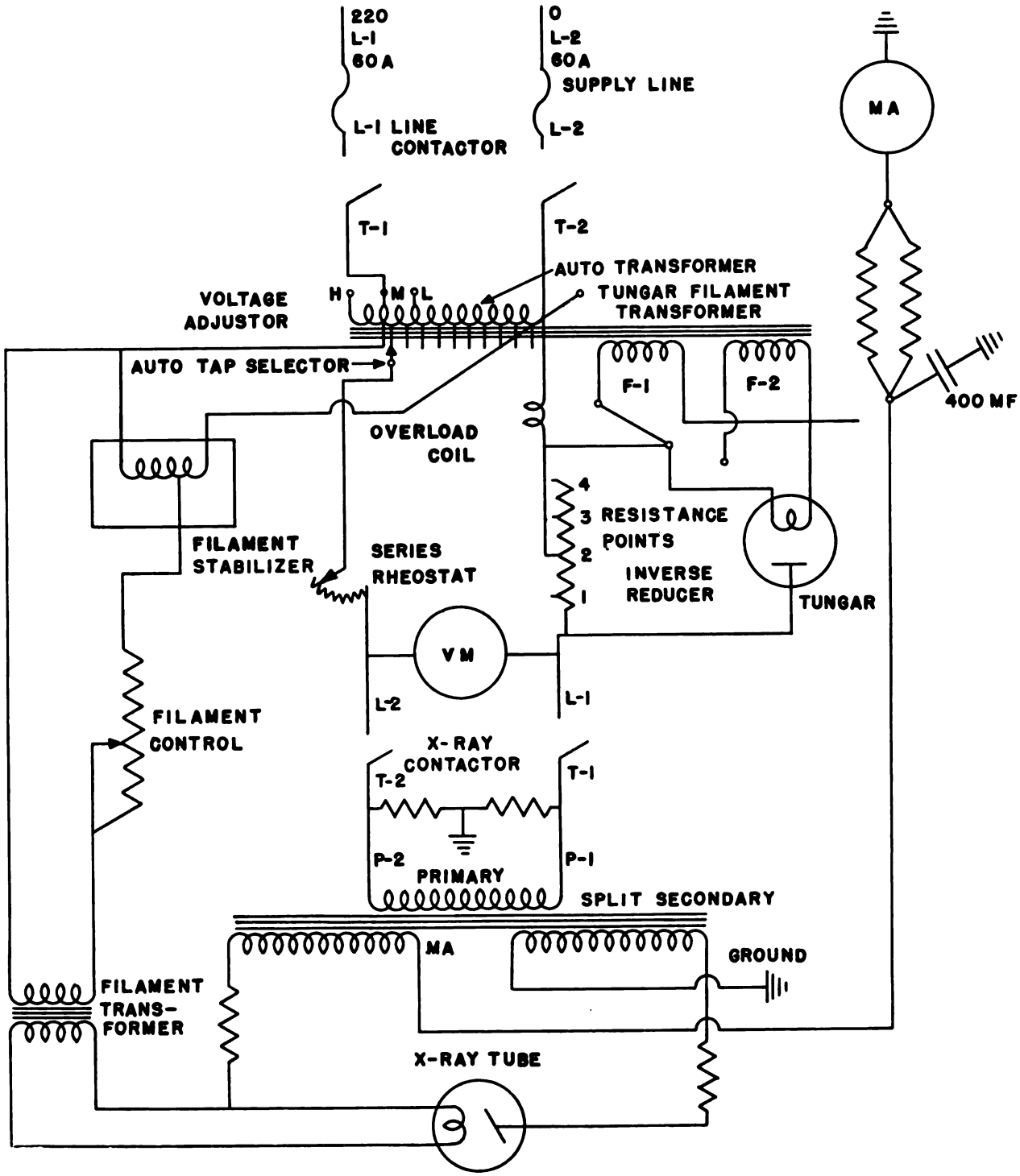

220
L-1
60 A
L-1 LINE
CONTACTOR
0
L-2
60 A
SUPPLY LINE
L-2
MA
T-1
T-2
AUTO TRANSFORMER
VOLTAGE
ADJUSTOR
H
M
L
TUNGAR FILAMENT
TRANSFORMER
AUTO TAP SELECTOR
F-1
F-2
400 MF
OVERLOAD
COIL
4
3
2
1
RESISTANCE
POINTS
INVERSE
REDUCER
TUNGAR
FILAMENT
STABILIZER
SERIES
RHEOSTAT
VM
L-2
L-1
FILAMENT
CONTROL
X-RAY
CONTACTOR
T-2
T-1
P-2
P-1
PRIMARY
SPLIT SECONDARY
MA
GROUND
FILAMENT
TRANS-
FORMER
X-RAY TUBE

FIGURE 158

b. High and low pressure oil trips in oil circulating system.

c. Overload switch to prevent overloading x-ray circuit.

d. Fuses to prevent overload on whole machine and certain other circuits.

e. Protective switch to insure all resistance being in on starting.

f. "Dead Front" control panel.

(2) Following is a list of radiation protective devices and features:

a. Shutter over tube port to absorb radiation except during actual exposure.

b. Small radiation leakage from unit due to lead sheet masking in the head.

c. Provision for door interlock to prevent energizing the x-ray circuit when target room door is open.

Chapter 18

THE OPERATION OF THE GENERAL ELECTRIC 250 KV UNIT

The G-E Model OX 250 Industrial Radiographic Unit consists of three distinct parts. These are:

(a) The control unit which contains all of the controls and indicating devices.

(b) The tube head which includes the tube and high voltage equipment immersed in oil.

(c) The oil-cooling unit.

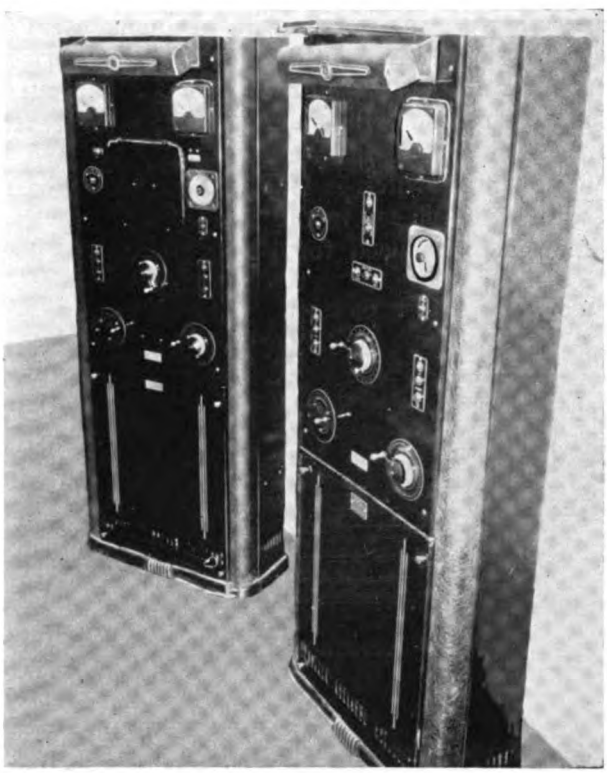


FIGURE 159

Control Unit

The instrument lamp illuminates the control and indicating devices on the panel. The lamp may be turned on at any time, by means of the lamp switch after the control unit is energized.

The double push button station at the left side of the panel controls the magnetic line switch. Pressing the "On" button energizes the control unit, starts the oil cooler, lights the filament of the x-ray tube, and puts into operation any other devices that may require starting before the x-ray switch is closed. Power is removed from the control unit by momentarily pressing the "Off" button. The red bulls-eye pilot lamp, just above the push button station, lights up when the line switch is on.

The voltmeter is connected directly across the primary leads to the high voltage transformer. It is arranged to be both pre-reading and load reading; that is, it reads as soon as the line switch is closed, and its reading is used to indicate the setting of the autotransformer control. After the x-ray switch is closed, the volt-meter reading is used to determine the kilovoltage across the tube by referring to the calibration chart.

The voltmeter is equipped with a double scale, 0-125 and 0-250 volts. The scale selector immediately below it is used to select the proper scale on the meter. When this switch is placed in the "High" position the 0-250 volt scale is used and when placed in the "Low" position the 0-125 volt scale is used.

The voltmeter always reads a few volts lower under load than at no load, due to the voltage

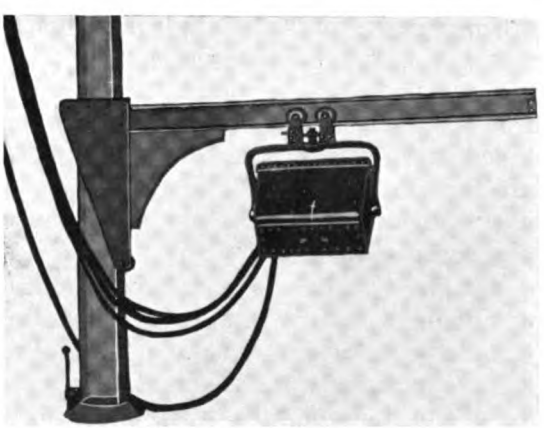


FIGURE 160

699810—46—11

regulation of the power line and of the circuit in the control unit. The calibration chart is based on the voltmeter reading under load conditions at which times the resistance control should be cut entirely out, or as nearly so as practicable.

The filament control controls the temperature of the x-ray tube filament and hence, the milliamperage through the x-ray tube. The filament control incorporates a rheostat whose resistance varies slightly with temperature and consequently the exact setting for any specific milliamperage will change somewhat as it warms up during operation. Turning the filament control clockwise increases the milliamperage.

The setting of the kilovolt selector determines the kilovoltage applied to the x-ray tube when it is energized. By adjusting this control, noting the reading of the voltmeter and taking into account the known drop as the load is put on, the autotransformer may be pre-set for any given kilovoltage as indicated by the calibration chart.

The push button station on the right side of the control panel controls the magnatic x-ray switch through which the high voltage transformer and the x-ray tube are energized. The red pilot lamp just above the push button station is lighted when the x-ray switch is closed.

The milliammeter indicates the current in milliamperes flowing through the x-ray tube. Its scale is calibrated from 0 to 15 milliamperes.

The time meter indicates the number of hours the x-ray tube has been energized. This meter is not adjustable, hence its reading should be recorded at the time the x-ray tube is installed and again at the time the tube is removed for replacement. The difference in the two readings indicates the number of hours the tube has been energized.

The exposure counter is energized and its reading advances one integer every time the x-ray contactor is closed, thus indicating the number of exposures. Its reading should be recorded at the time the x-ray tube is installed and again when the tube is removed. The difference between the two readings represents the number of exposures made with the x-ray tube.

The exposure timer is an automatic electric timer with dial calibrated from zero to 20 minutes. There are two scales and indicating hands, the outer scale representing minutes and the inner scale representing seconds. To set the timer, loosen the knob labeled "Tighten after Adjusting" by turning it counter-clockwise and then turn the collar to the desired minutes and seconds. Tighten the knob clockwise after the timer has been adjusted to the desired exposure time.

The exposure is started by momentarily pressing the "On" button of the x-ray push button station. The exposure will automatically be terminated at the end of the exposure time for which the timer is set or it may be terminated at will by momentarily pressing the "Off" button of the x-ray push button station. Termination of the exposure for any reason will cause the timer to reset automatically for the time interval indicated.

The timer switch is located below the timer and must be placed in the "On" position if the timer is to be used for timing the exposure.

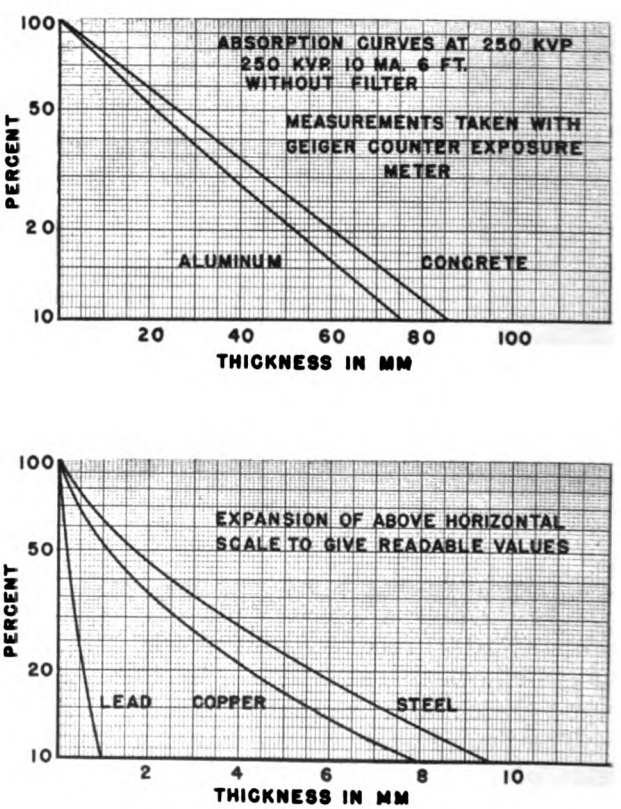


FIGURE 161

Should it be desired to operate the x-ray tube without control of exposure time by means of the timer, the timer switch is left in the "Off" position, and the exposure is started and stopped by pressing respectively the "On" and "Off" buttons of the x-ray push button station.

The resistance control has twenty-three points of control and controls the amount of resistance in the primary circuit of the high voltage transformer. It is used in starting the x-ray exposures and also to control the voltage supplied to the x-ray tube when variations occur during an exposure. When the control is on position 1, the entire resistance is in circuit, and on position 23 all resistance is cut out. To insure that the x-ray tube shall be energized with all resistance in circuit, the x-ray switch is interlocked with the resistance control so that the latter must be on position 1 before the x-ray tube can be energized.

Tube Head

The tube head contains the x-ray tube, the high voltage transformer, and the x-ray tube filament transformer, all immersed in oil.

The x-ray tube has a focal spot with effective size of approximately 5 mm. x 5 mm. The x-ray tube is made for self-rectified operation. That is, it is connected directly to the terminals of the high voltage transformer except for the inclusion of a protective ballast or surge resistance, and it is cooled by forced circulation of oil through passages located immediately behind the target on the anode.

The high voltage transformer is a closed core type and is operated with the center of the secondary held permanently at ground potential, thus the use of a milliammeter connected directly into the high voltage circuit for measuring the x-ray tube current, yet permits the meter to be mounted in the control panel.

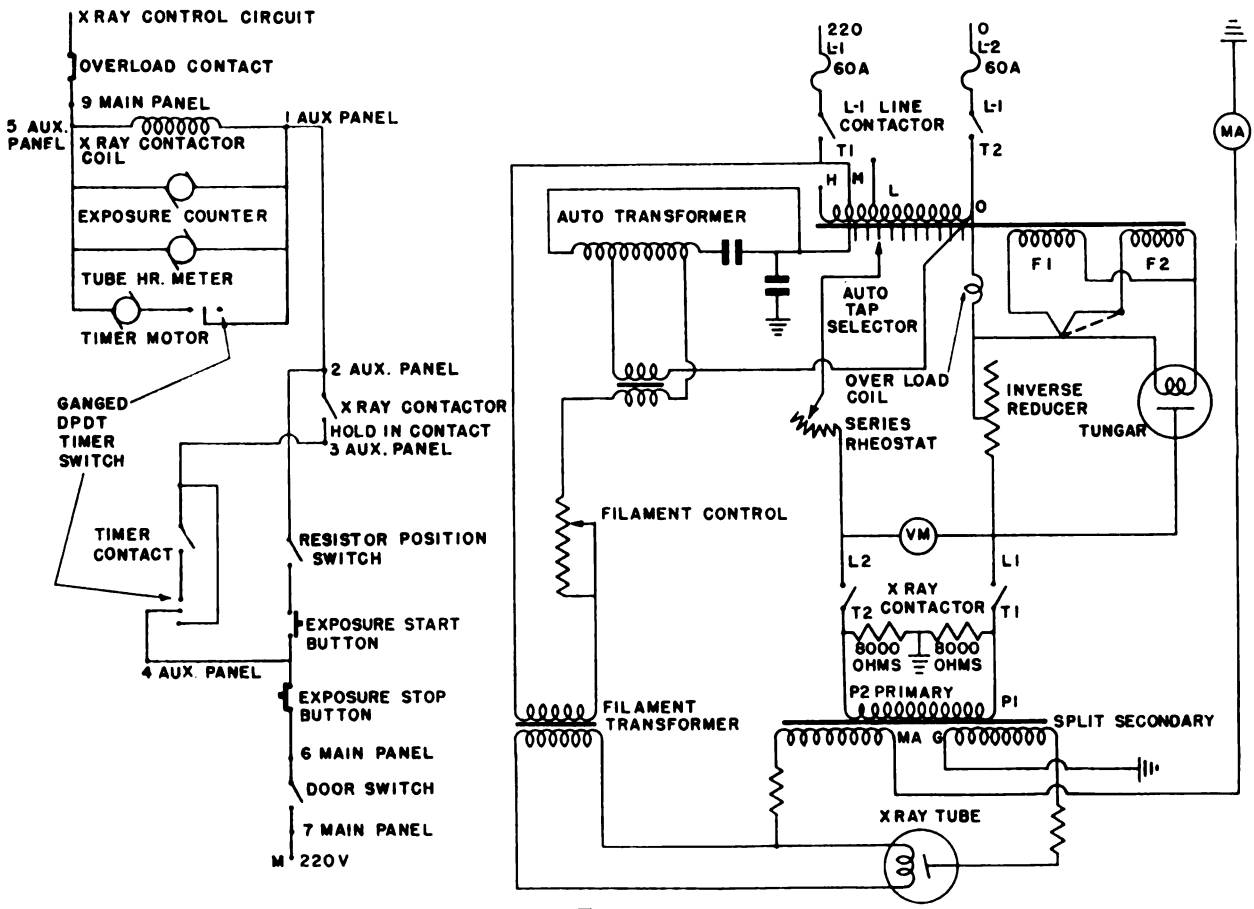


FIGURE 162

Oil Cooling Unit

The oil cooler forces oil under considerable pressure through a cooling coil located in the anode of the x-ray tube immediately behind the target. The oil is conducted to and from the tube through flexible hoses. On returning from the x-ray tube it passes through the radiator in the oil cooling unit where the heat picked up from the tube is removed.

The oil-cooling unit consists of a radiator, specially adjusted oil pump, and electric motor, ventilating fan, and two pressurestats. The pressurestats prevent operation when the oil pressure rises too high, as in case of blockage, or falls too low due to failure of the oil cooling system or oil hoses.

Three hoses are used between the oil-cooling unit and the tube head. Two of these carry the cooling oil that is circulated through the anode of the tube. The third permits oil to flow between the tube head and radiator as it changes volume due to changes in temperature. The radiator in the cooling unit acts as an expansion reservoir.

The oil level is observed on the oil level gauge. Oil may be added to the unit by removing the radiator cap.

A breather permits escape or entrance of air into the oil cooler as the volume of oil changes. It reduces the contamination of the oil by preventing the admission of foreign materials as the unit "breathes".

Operation

The OX 250 may be operated continuously at 250 Kv.P 10 ma when operating at lower voltage the tube current should be reduced to avoid burning out filament.

The procedure for operation is as follows in step by step.

1. Turn the filament control well down toward the zero position.
2. Close the line switch.
3. Set the kilovolt selector to produce the proper kvp.
4. Turn the resistance control to button 1.
5. Set the exposure timer to the desired time valve.
6. Turn the timer switch on.
7. Close the x-ray switch.

TABLE XXXIX

CALIBRATION CHART FOR OX 250 INDUSTRIAL X-RAY UNIT WITH FORCED OIL COOLING

Useful Kv.P	*For 5 ma.* Voltmeter Reading Under Load	*For 8 ma.* Voltmeter Reading Under Load	*For 10 ma.* Voltmeter Reading Under Load
60	59.0	61.5	62.0
65	63.0	65.5	66.0
70	67.0	69.5	70.0
75	71.0	73.5	74.0
80	75.0	77.0	78.0
85	79.0	81.0	82.0
90	82.5	85.0	86.0
95	86.0	84.0	90.0
100	90.0	93.0	94.0
105	94.0	96.5	98.0
110	98.0	100.5	101.5
115	101.5	104.0	105.5
120	105.5	108.0	109.5
125	110.0	112.0	113.0
130	113.0	116.0	117.0
135	117.0	120.0	121.0
140	121.0	124.0	125.0
145	125.0	128.0	129.0
150	129.0	131.5	133.0
155	132.5	135.5	137.0
160	136.5	139.5	141.0
165	140.0	143.0	145.0
170	144.0	147.0	148.5
175	148.0	151.0	152.0
180	152.0	155.0	156.0
185	155.5	159.0	160.0
190	159.5	162.5	164.0
195	163.0	166.5	168.0
200	167.0	170.5	172.0
205	171.0	174.5	176.0
210	175.0	178.0	180.0
215	178.5	182.0	184.0
220	182.5	186.0	188.0
225	186.0	190.0	192.0
230	190.0	194.0	196.0
235	194.0	197.5	200.0
240	198.0	201.5	204.0
245	201.5	205.5	208.0
250	205.0	209.0	212.0

CAUTION: ALWAYS OPEN THE X-RAY CONTACTOR SWITCH BEFORE CHANGING THE SETTING OF THE AUTO-TRANSFORMER CONTROL.

8. Simultaneously adjust the filament control to give proper milliamperage and advance resistance control to 23.
9. Adjust tube current from time to time by filament control.

10. The exposure timer will terminate the exposure.

11. Deënergize the control unit.

12. Turn the filament control toward zero position.

Maintenance

1. Check inverse reducer tube once a month for secure connections.

2. Check oil level once every three months, and oil motor, and fan bearings.

3. Clean oil strainer every six months.

4. Timer should be oiled once every six months.

NOTE

The minimum kilovoltage at which the x-ray tube can be operated at 10 ma is specified on a separate instruction sheet furnished with the tube. If it is desired to operate the tube below this minimum kilovoltage, the filament regulator should not be raised above that setting a which 10 ma is obtained at this kilovoltage.

699810—46—12

Chapter 19

THE OPERATION OF THE KELLEY KOETT 150 KV UNIT

The Kelley Koett 150 KV unit consists of the following parts:

(1) The portable type control unit which contains the meters, auto-transformer, main switch, filament control rheostat, auto-transformer tap selector, fuses, etc.

(2) The shockproof high tension transformer, a single container in which is immersed in oil the high tension transformer, filament transformers and two rectifier tubes.

(3) The interconnecting cables of which there are four between the control unit and transformer with polarized plugs on their ends that engage in only the proper sockets on the units. There are two high tension cables which connect the x-ray tube and transformer unit. These cables have special insulating connectors at each end to insulate the high voltage. There is also one cable to the control unit from the power source which has a polarized plug that fits in its proper socket on the control unit.

(4) The Industrial Thermax x-ray tube which is oil immersed, shockproof, single focus and having a flexible cooling coil in the oil space through which tap water is run. The tube head is provided with a bellows arrangement to allow for oil expansion.

Operational Instructions

1. Turn on cooling water to tube if no magnetic water valve is used.
2. Turn main line switch to "On" position. This energizes the control panel and the filaments of the rectifier and x-ray tubes; and magnetic water valve if used.
3. Set auto-transformer tap selectors to give desired Kv.P at the x-ray tube. This proper setting can be obtained from the chart showing x-ray tube Kv.P vs. transformer primary voltage shown on the voltmeter.
4. There are two tap selectors mounted on concentric shafts. The selector with the knurled knob makes adjustments in 3 volt steps and the selector with the handle makes adjustments in 20 volts steps.
5. Set timer to desired exposure time up to 15 minutes.
6. Close x-ray toggle switch.
7. Check setting of filament control to see that it is set to a point not higher than that which will give the desired tube current.
8. Bring rheostat control all the way around to the START position. This closes the REFERENCE switch which completes the magnetic contactor closing circuit. The magnetic contactor in closing completes the circuit to the primary of the high tension transformer.
9. Simultaneously bring the rheostat control around to the OPERATE position and adjust the filament control to obtain the desired x-ray tube current.
10. Maintain proper tube current during the exposure by adjustment of the filament control.
11. When the timer "runs off" it breaks the circuit to the magnetic contactor coil, thus securing the x-ray circuit.
12. After the exposure has terminated, the x-ray toggle and main line switches should be turned OFF.

NOTES

1. *Always make sure the auto-transformer tap selectors are centered on their contacts.*
2. *Never change the setting of the auto-transformer tap selectors while the x-ray circuit is energized.*
3. *Before operating at higher than 100 Kv.P the x-ray tube has to be warmed up.*

The "warming up" is accomplished by energizing the x-ray tube for at least ½ minute in 10 Kv.P steps above 100 Kv.P.

4. *Always make sure that cooling water is on to the x-ray tube before making an exposure.*

Focal Film Distance

It has been found that the exposure times are not excessively long when radiographing anything up to the equivalent of one half inch of steel thickness at a focal-film distance of six

feet. By using this longer focal-film distance, distortion, especially in thicker objects, is considerably reduced and that fuzziness of line due to focal-spot size is practially eliminated.

Current

The x-ray tube current usually used is 5 M.A. but this may be increased at the lower kilovoltages. The maximum allowable tube currents are shown on the graph of tube Kv.P vs. primary voltage, Figure 163.

Spot Size

The projected focal-spot size is 2.3 mm. square.

Radiation Output

The radiation output at 150 Kv.P, 5 M.A., at a distance of 6 ft. from the focal-spot is 193 roentgen units per hour.

Absorption Coefficients

Table XL was obtained by direct measurement through absorption coefficients, effective wavelengths etc.

Technique Charts

Technique charts for steel and aluminum are shown in Chapter 9, Figue 92. Following are some half-value layers at 150 Kv.P in the event that this system of determining exposures is used: These values are based on no filtration.

Aluminum 0.75″	Copper 0.036″
Steel 0.045″	Lead 0.010″

Wiring Diagram

A complete wiring diagram of the whole unit is shown in Figure 164 (overload relay normally closed). The method of eliminating the "in-

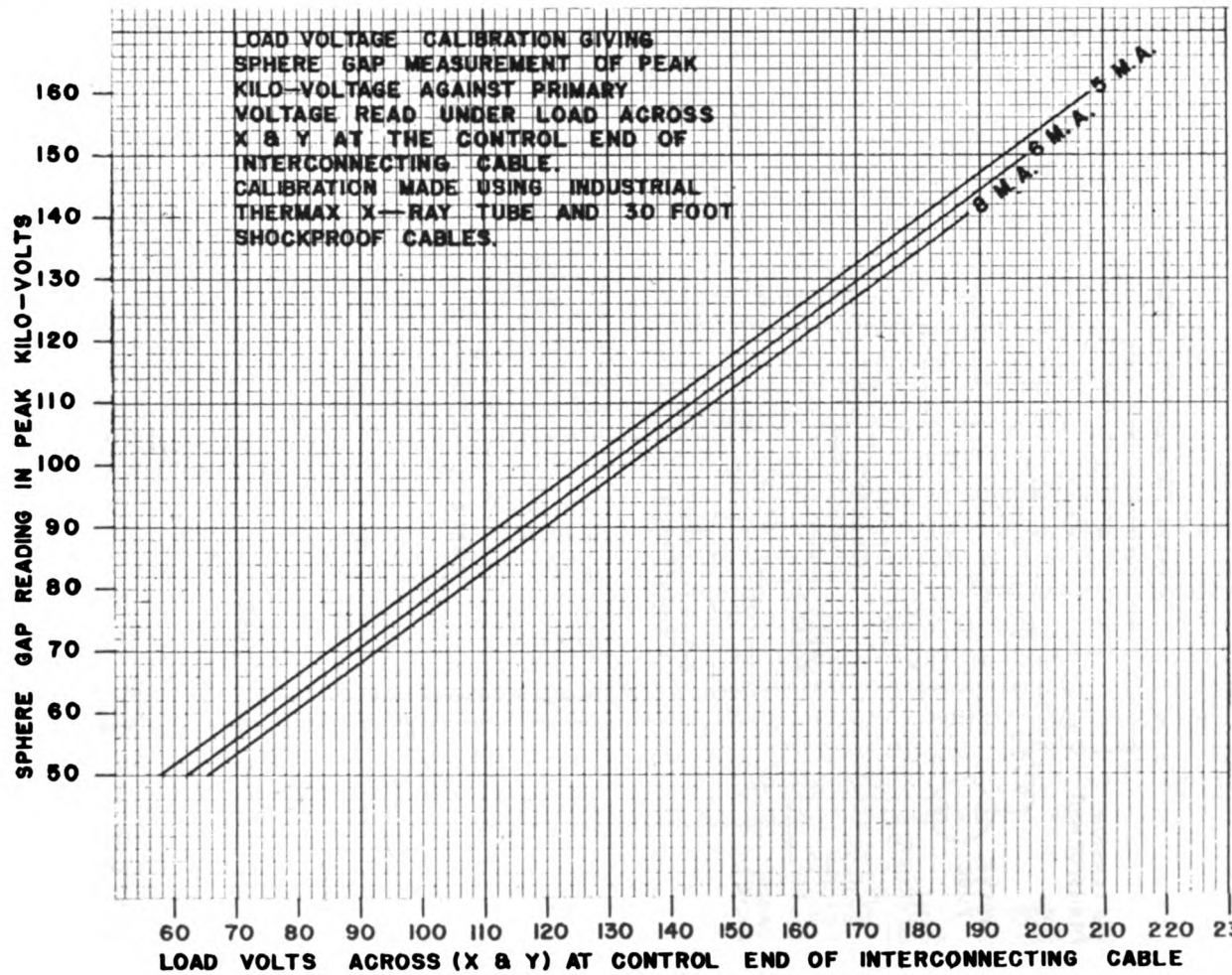

LOAD VOLTAGE CALIBRATION GIVING SPHERE GAP MEASUREMENT OF PEAK KILO-VOLTAGE AGAINST PRIMARY VOLTAGE READ UNDER LOAD ACROSS X & Y AT THE CONTROL END OF INTERCONNECTING CABLE.
CALIBRATION MADE USING INDUSTRIAL THERMAX X-RAY TUBE AND 30 FOOT SHOCKPROOF CABLES.
5 M.A.
6 M.A.
8 M.A.
SPHERE GAP READING IN PEAK KILO-VOLTS
160
150
140
130
120
110
100
90
80
70
60
50
60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230
LOAD VOLTS ACROSS (X & Y) AT CONTROL END OF INTERCONNECTING CABLE

FIGURE 163

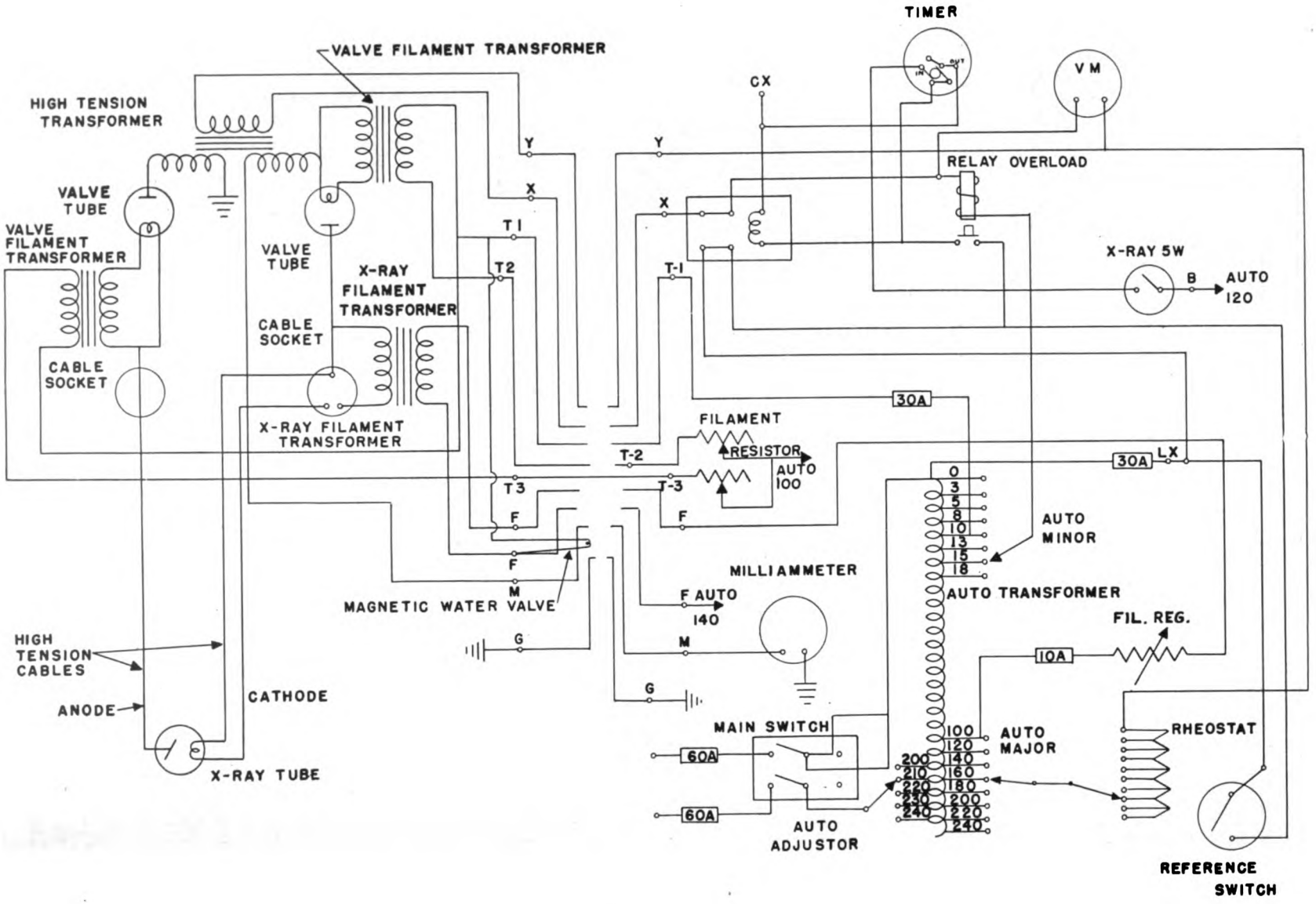

TIMER
VALVE FILAMENT TRANSFORMER
HIGH TENSION TRANSFORMER
VALVE TUBE
VALVE FILAMENT TRANSFORMER
CABLE SOCKET
VALVE TUBE
X-RAY FILAMENT TRANSFORMER
CABLE SOCKET
X-RAY FILAMENT TRANSFORMER
CX
V M
RELAY OVERLOAD
X-RAY 5W
B
AUTO 120
Y
X
T1
T2
T-1
30A
FILAMENT
RESISTOR
AUTO 100
T-2
T3
T-3
F
F
F
M
MAGNETIC WATER VALVE
F AUTO 140
MILLIAMMETER
M
G
G
HIGH TENSION CABLES
ANODE
CATHODE
X-RAY TUBE
MAIN SWITCH
60A
60A
AUTO ADJUSTOR
0 3 5 8 10 13 15 18
AUTO MINOR
AUTO TRANSFORMER
30A
LX
FIL. REG.
10A
100 120 140 160 180 200 220 240
AUTO MAJOR
RHEOSTAT
REFERENCE SWITCH

FIGURE 164

verse peak" in this unit is the use of two rectifying tubes, one in each high tension line to the x-ray tube and arranged in such a manner that both "fire" only during that half cycle in which the x-ray tube is conducting. During the other half cycle the rectifying tubes are non-conducting therefore completely insulating the x-ray tube from the high voltage transformer. The "inverse peak" is an abnormally high voltage peak occurring during the no-load half cycle in which the x-ray tube is not firing.

3. It has happened in some cases that the water hose connecting nuts have been tightened down too much on the x-ray tube, causing the flexible water cooling tubing connection to turn in the tube housing, thus allowing the oil and water to mix. This mixture has a very low resistance, so that when the voltage is applied to the tube, there is very violent arcing in the tube housing between the tube connections and grounded tube housing. Use care in making the water hose connections to the tube.

TABLE XL

Kv.P	mm. Cu. Filter	Material	Linear u	Mass u/p	Eff. wave-length	Eff. Kv.	Kv.P 1.3 x Kv. Eff.
150	2	Pb	31.8	3.8	.105	120.7	160
150	2	Cu	3.64	.408	.115	110	140
150	2	Fe	2.49	.328	.1125	111	144
150	2	Al	.43	.1655	.1125	111	144

Troubles and Remedies

1. The greatest amount of trouble experienced in this unit is the breaking down of the insulation in the high tension cables, cable connections and in the x-ray tube itself. The reasons for this breakdown are usually moisture on cable and tube connections or unbalance of the two rectifying tube filaments causing high voltage peaks. To prevent moisture on cable or tube connections, first clean them with a cloth moistened with carbon tetrachloride before assembling the unit. After the connections are cleaned they should have clean white un-medicated vaseline spread over their surfaces with a dry wooden pallet. This prevents moisture from getting in and provides a "vapor lock". In case of rectifying tube filament unbalance, the filaments should be set to operate at their proper voltage (10v) and current (11.5 amps) by adjusting the adjustable resistors in the control panel.

2. Some difficulty is experienced with the control and power supply cable connections. In some instances the female connections have spread enough to open the circuit. These connections can sometimes be bent back in place but in other cases especially when the connections have been burned by arcing, the connection will have to be replaced with a new one.

4. In case of a very violent spark on the high voltage circuit the overload relay operates to open the x-ray control circuit. When resuming operation the relay will have to be reset to again complete that portion of the x-ray control circuit.

Safety Devices

This machine has no radiation safety devices. There are some electrical safety features which are listed below:

1. The power supply to the unit, the tube filament circuits and the x-ray control circuits are fused to protect against overload.

2. The x-ray circuit is protected from overload by an overload circuit breaker in the primary circuit of the high voltage transformer.

3. The high tension circuit is protected from voltage surges on starting by a rheostat in the primary circuit and a reference switch contact which is made when the rheostat is turned to the position of maximum resistance.

4. All external parts of the unit are grounded to prevent electrical shock.

Fluoroscope

The fluoroscopic unit consists of a light tight booth with a lead lining around the lower part to absorb the radiation from the tube. The x-ray source is a Kelley Koett 150 Kv.P unit

with the control panel mounted in the booth. The fluorescent screen is covered with two pieces of lead glass and the edges are masked with strips of lead to prevent leakage of the x-ray into the booth. Located beneath the screen is a spring loaded sponge rubber mounting for objects with a control knob inside the booth so that the object may be rotated while viewing. The x-ray tube is mounted to give a screen-source distance of 30 inches, which is the maximum possible with this set-up.

Operation

The operation of the x-ray unit is the same as that previously given for this unit except that there is no magnetic water valve for the cooling water. In this case the water valve has to be turned on and off by hand. The object can either be set up in the rotating device or laid on a thin piece of plywood for support. The beam of radiation should be coned down at the tube so that it just covers the object being viewed. The coning is accomplished by adjusting the position of lead plates placed in front of the tube. The x-ray tube should not be shifted nearer to the screen because the unsharpness of line due to focal spot size is very evident, and the distortion is very objectionable especially in thicker objects.

Viewing

Due to eye fatigue, one person should never be required to view the screen for any prolonged period of time without intervals of rest.

Before viewing the screen, in order to obtain the best sensitivity, the eyes should be dark adapted. A discussion of production of fluorescence and eye accommodation may be found in Chapter 3. In the case of irregularly shaped objects it may be necessary to mask parts of the screen with cardboard or stiff paper in order to cut down the background screen intensity. It has been found that a film of thin clear oil between the two lead glass plates very effectively reduces the double refraction of the image on the screen, caused by the double thickness of glass.

Treatment of Lead Glass

Lead protective glass when subjected to radiation over a period of time gradually takes on a brown tint. This discoloration causes blurring of the image, thus decreasing the sensitivity obtainable. The brown tint may be removed from the glass by placing it in an oven at about 350°F. At the end of several hours baking the discoloration will have disappeared.

Maximum Viewable Thicknesses

The thicknesses will vary with the Kv.P used and the material being viewed. The machine normally is operated at the same tube current regardless of Kv.P.

Following is a chart showing the upper range of thicknesses of different materials that can be comfortably viewed at 150 Kv.P and 5 M.A. tube current and sensitivities:

5 mm. Copper	10% Sensitivity
7 mm. Copper	15% Sensitivity
3-½ in. Aluminum	15% Sensitivity
.5 in. Steel	14% Sensitivity

Chapter 20

THE OPERATION OF THE GENERAL ELECTRIC 100 KV UNIT

The 100 KV Fluoroscope consists of two units: a control cabinet and an oil immersed tube and transformer. The entire unit is shockproof.

On the control cabinet is mounted the x-ray circuit breaker and line switch, the millimeter, auto transformer selector and filament rheostat control on right side.

To operate the unit close the x-ray switch which starts the motor and pump, energizes the filament and high voltage transformer.

The millimeter indicates the current according to the setting of the filament rheostat. The rheostat may be changed to adjust the tube current to the desired value during operation.

The circuit breaker is of the thermal type and protects the unit from excessive overload. If the circuit breaker should trip, it will be in the midposition between "off" and "on". To reset; the switch is placed in "off" and then returned to "on". The thermal unit should be allowed to cool before resetting.

The voltage across the x-ray tube is controlled by the auto transformer selector. This selector should never be moved while the unit is in operation.

The voltage settings and current rating are listed below:

Position	*Kilovolts*	*Max. Current M.A.*
A	60	10.0
B	70	9.0
C	80	8.0
D	90	7.0
E	100	7.0

For normal operation the unit is warmed up by operating three minutes on position "B" at 5 M.A. Then open the circuit and select the voltage and current desired.

Maintenance

The oil level should be maintained at one inch below the bottom of the cover when temperature is 70°F. The oil is transil transformer oil Cat. A8002. The pump and motor bearings should be oiled once every two months.

For best results the screen and object should be close together as possible. The screen is covered by lead glass equivalent to 1.5 mm of lead. The radiation should be confined to the area of the object to reduce the stray light.

The oil screen should be cleaned once a year. The maximum temperature should not exceed 167°F.

There is no safety device for protection against the radiation. The operator must use precaution when operating the unit. The transformer and tube unit should be enclosed in lead with the beam coned down by the lead shutters.

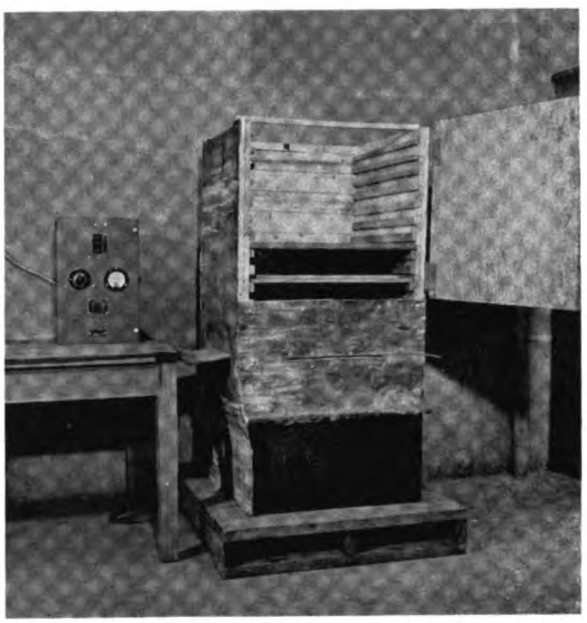


FIGURE 165

For description of Kelley Koett 150 KV Fluoroscope see Chapter 19.

Photography of Fluoroscopic Screen, Test Results

1. A Patterson Type-B fluoroscope screen, and a 9x12 cm Linhof München camera with a F 4.5 135 mm Zeiss Tessar lens was used for this test.

2. All exposures were taken at a 25 inch lens distance with 7 M.A. tube current at 100

kv. The film used was Super XX and Verichrome; however, the extra sensitivity to green of the Verichrome made both film speeds approximately equal.

3. The object used consisted of three ½ inch aluminum plates. The lower face of the first being sloted to depths of one to ten percent of the one-half inch thickness, ⅛" wide. The second and third pieces were placed to produce a three step effect. The object was kept about two inches below the fluorescent screen.

4. Exposures of ten minutes were made on the steps from 48 to 35 inch (screen to tube distance) with sensitivities in all cases of two percent on the one-half and one inch thicknesses. The 1½ inch layer produced too light an image to give any definite results.

5. At 35 inches and again at 26 inches a check was made of the exposure time indicating 4 minutes to be an optimum exposure. However at 26 inches, sensitivities of one percent were obtained.

6. A further microscopic study of the Patterson screen was made indicating a particle size of about one-thousandths inch and a spacing of 2 to 5 thousandths.

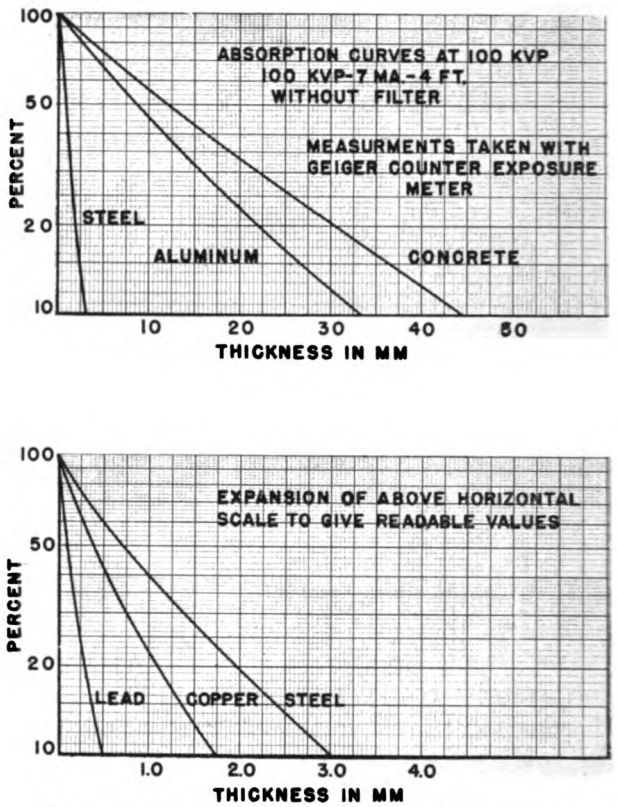


FIGURE 166. G-E OX-100 Absorption Curves

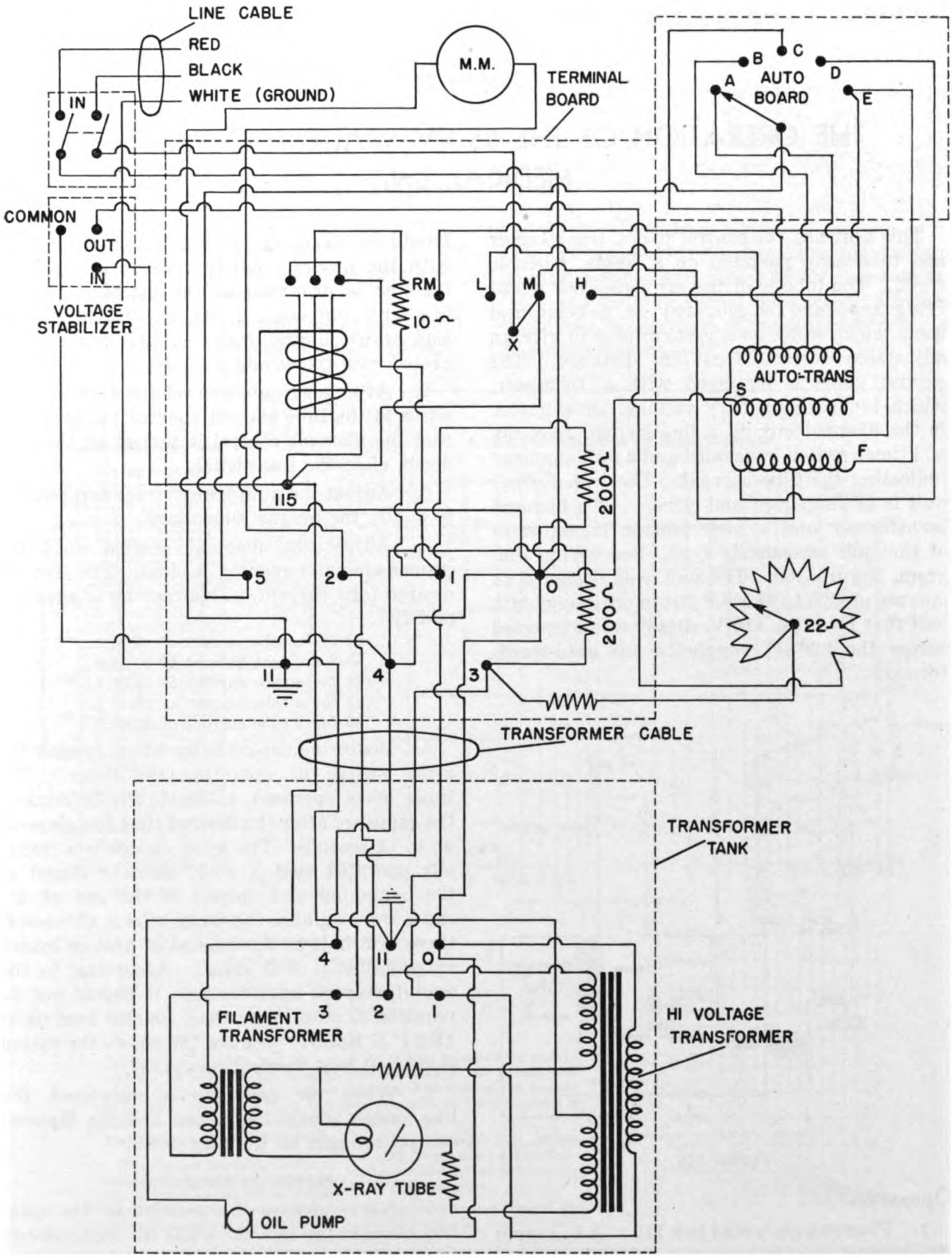


FIGURE 167

699810—46—13

Chapter 21

THE OPERATION OF THE 85 KV WAITE AND BARTLETT MEDICAL UNIT

This unit has the control panel, transformer and tube head mounted on a single, movable stand. The tube is of the air cooled self rectifying type and is mounted on a horizontal boom which slides on a vertical pipe to give an adjustable vertical focal-film distance. The control panel is equipped with a voltmeter, which indicates primary voltage, an ammeter in the filament circuit, a line switch, an x-ray and timer switch in parallel and a milliammeter indicating the tube current. The transformer unit is oil immersed and consists of a filament transformer and a high tension transformer of the split secondardy type. See wiring diagram, Figure 168. The unit was designed to operate at 42.5 to 85 Kv.P but in order to obtain half that Kv.P the 110 V. supply was connected across the 220 V. supply to the auto-transformer.

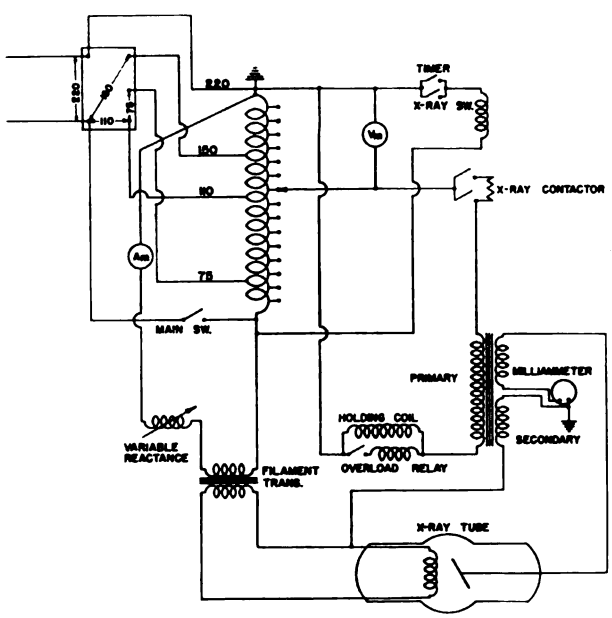


FIGURE 168

Operation

1. Plug in supply lead to a 110 v. A.C. source and connect ground wire to a suitable ground. It will be necessary to plug the supply lead in with the proper polarity because one side of the line is grounded in the machine. There is a lamp connected in series with the ground lead which lights if the supply lead is connected with the wrong polarity.

2. After making sure that the filament lead wires to the tube are not shorted together and that the filament control is turned all the way down, close the line switch.

3. Adjust the auto-transformer tap selector to obtain the proper kilovoltage.

4. Adjust the filament control until the proper ammeter reading is obtained to give the desired tube current. This reading is approximately

54 for a tube current of 5 M.A.
59 for a tube current of 10 M.A.
61 for a tube current of 15 M.A.
63 for a tube current of 20 M.A.
65 for a tube current of 25 M.A.

5. Begin the exposure by either closing the x-ray switch or operating the timer. The timer when operated, automatically terminates the exposure after the desired time has elapsed, up to 12 seconds. The x-ray switch is a manually operated switch, so it must be closed at the beginning and opened at the end of the exposure. Because the x-ray tube is air cooled, there is a limit to the amount of heat or length of exposure it will stand. According to the manufacturer's specifications it should not be required to store more than 100,000 heat units (Kv.P X Ma. S). Figure 169 shows the rating chart and heat dissipation curves.

6. When the exposure is completed, the line switch should be opened and the filament control brought all the way down.

NOTES ON OPERATION

1. *Never change the position of the auto-transformer tap selector while the x-ray circuit is energized.*

2. *Before closing the line switch, make sure the filament control is all the way down.*

3. *Always make certain the machine is grounded before operation.*

4. *Never make an exposure or a series of exposures of such length that the tube becomes overheated.*

5. *Make sure the tube target is centered on the hole in the lead protective glass shield before making the exposure.*

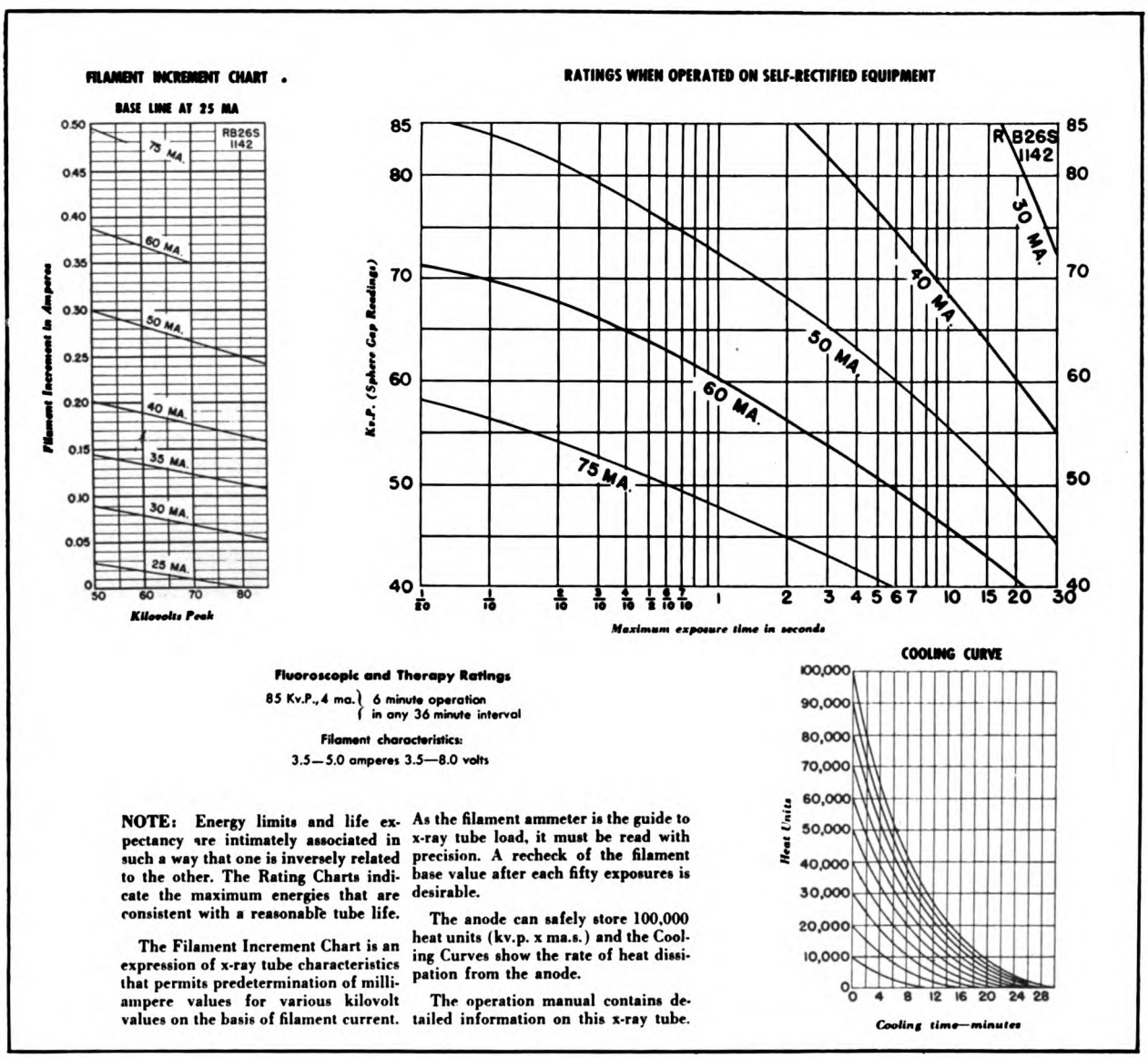
6. *Do not touch or come near the high tension wires to the tube during the exposure.*

Tube Current

For short exposures the tube may be operated up to 30 M.A. in making longer exposures the tube current should not exceed 10 M.A. All the exposure data is based on a tube current of 10 Ma.

Focal-Film Distance

In order to obtain exposure times of practical lengths, when operating at 30 Kv.P or less the focal-film distance should not exceed 18 inches. At higher kilovoltages a focal-film distance of 36 inches may be used.



NOTE: Energy limits and life expectancy are intimately associated in such a way that one is inversely related to the other. The Rating Charts indicate the maximum energies that are consistent with a reasonable tube life.

The Filament Increment Chart is an expression of x-ray tube characteristics that permits predetermination of milliampere values for various kilovolt values on the basis of filament current. As the filament ammeter is the guide to x-ray tube load, it must be read with precision. A recheck of the filament base value after each fifty exposures is desirable.

The anode can safely store 100,000 heat units (kv.p. x ma.s.) and the Cooling Curves show the rate of heat dissipation from the anode.

The operation manual contains detailed information on this x-ray tube.

FIGURE 169

Focal Spot Size

By actual measurement the focal spot is ¼ inch square.

Radiation Output

Figure 170 contains a curve showing Kv.P vs. r per minute at a distance of 18" from the focal spot with a tube current of 10 M.A.

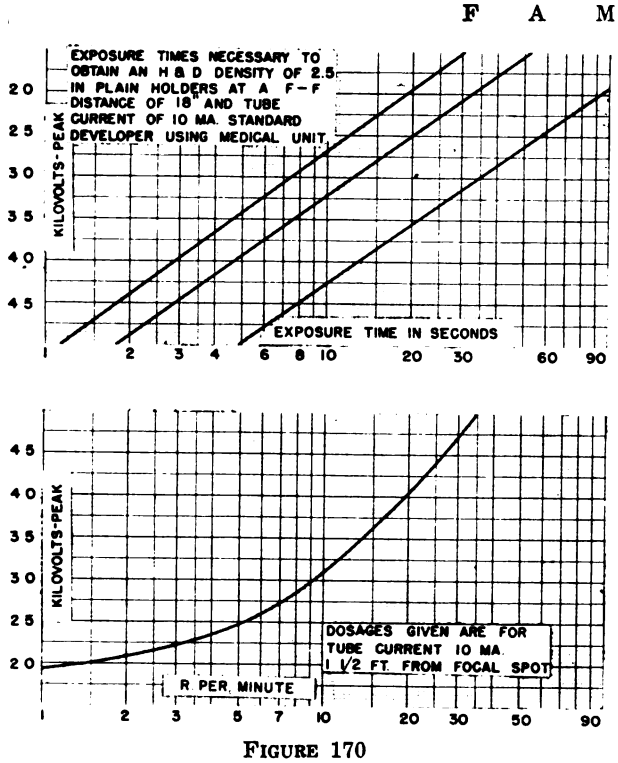

F A M
EXPOSURE TIMES NECESSARY TO OBTAIN AN H & D DENSITY OF 2.5 IN PLAIN HOLDERS AT A F-F DISTANCE OF 18" AND TUBE CURRENT OF 10 MA. STANDARD DEVELOPER USING MEDICAL UNIT
KILOVOLTS-PEAK
20
25
30
35
40
45
EXPOSURE TIME IN SECONDS
1 2 3 4 6 8 10 20 30 60 90
KILOVOLTS-PEAK
45
40
35
30
25
20
DOSAGES GIVEN ARE FOR TUBE CURRENT 10 MA. 1 1/2 FT. FROM FOCAL SPOT
R PER MINUTE
1 2 3 5 7 10 20 30 50 90

FIGURE 170

Film Curves

See Figure 170 for a curve showing the exposure times necessary to obtain an H and D density of 2.5 on Eastman Type "F", "A", and "M" at a focal film distance of 18". The exposure time at any other distance varies inversely as the square of the distance.

It must be remembered that this low Kv.P range the radiation is not very penetrating. At 20 Kv.P an object thickness equivalent of 1 mm. of aluminum necessitates an impractically long exposure and at 45 Kv.P the maximum thickness which may be radiographed with a practical exposure time is just a few millimeters of aluminum. As an aid in determining the proper exposure time the above chart shows the exposure time necessary to obtain a background density of 2.5 at different kilovoltages. The kilovoltage selected should be one which will provide a high background density and at the same time produce a suitable radiograph of the object.

Maintenance

If a higher kilovoltage is desired, the 110 volt supply can be changed back to its proper tap to the auto-transformer, but it must be remembered that the filament supply lead must also be changed to obtain the proper voltage across it.

One trouble encountered is the breaking of the soldered connections at the high tension bushings of the transformer. These may be resoldered.

Occasionally the x-ray contactor should be checked to make certain that the contact with the series resistance closes first.

Safety Devices

The only electrical safety device is an overload circuit breaker to protect the machine from overload.

The only radiation safety device is a lead glass shield around the x-ray tube. The lead glass does not absorb all the radiation; so it is important that the operator either wear lead protective clothing or move back to some disance during longer exposures, especially at higher kilovoltages.

Special Uses

The machine can be used for micoradiography or for obtaining diffraction patterns. Because of the tungsten target tube the radiation output at the wave-lengths desired is very small; consequently the exposure times are excessively long. Ordinarily in micoradiography and x-ray diffraction a suitable soft metal target is used which will give a high characteristic radiation output at the desired wave-length where as the tungsten target tube emits a relatively small amount of radiation of the continuous spectrum in this range.

Chapter 22

SPECIAL RADIOGRAPHIC INSTRUMENTS

Condenser R-Meter

The commonly used condenser R-meter comprises a thimble chamber mounted on a chamber tube and an electroscope. The electroscope is connected to the electrodes of the chamber, when the chamber tube is inserted into the bayonet socket provided for it. The collector electrode, its lead in the chamber tube, and the lead to the electroscope have a capacitance of about 50 micromicrofarads with respect to the other side of the electroscope, the metal case of the instrument, the chamber tube and the conducting inner surface of the chamber; all of which are electrically connected. A manually operated frictional charging device is provided to charge the collector electrode assembly to a potential of approximately 400 volts. This charging device is an application of the method of separation of electric charges by friction.

FIGURE 171. Victoreen R-meter for measurements of x-ray and gamma ray intensities in roentgens

Since the capacitance of the R-meter is small (approximately 50 micromicrofarads), the charging device has to supply a relatively small charge (approximately 2 x 10^{-8} coulombs) to produce a difference in potential of 400 volts. The image of the fibre of the electroscope is focused on a glass scale and the position of the shadow of the fiber on the scale is observed through a microscope eyepiece by light from an incandescent flashlight bulb mounted within the case. When the collector electrode assembly is charged to about 400 volts, the fiber shadow appears at zero on the scale. When the chamber is placed in an x-ray beam of constant intensity for a measured interval of time (usually one or two minutes), the air in the measuring volume is ionized; the ions are attracted to the electrodes before they recombine and the difference of potential across the electroscope consequently decreases. The shadow of the fiber therefore moves from the zero point to some point on the scale which is marked in roentgens during the measured interval of time. The indication of the instrument at the end of the time interval divided by the time interval in minutes is the dose-rate in roentgens per minute. Interchangeable chambers to produce full-scale deflections for doses of 25 r, 100 r, 250 r and 1000 r are available.

Operation

1. Remove cap from the end of the chamber and insert it into the instrument.
2. Depress button on the left side of the instrument to light the screen and at the same time press in and turn the charging knob until the fiber line reaches the "O" position.
3. Remove chamber from the instrument and replace its cap over the terminal end.
4. Place chamber in position to measure the radiation, noting the exposure time.
5. Again remove cap from the chamber and insert into the instrument after checking to be sure the line is still at the "O" position. The dosage may then be read directly in roentgens from the proper scale on the screen.
6. After using, return the instrument and the chamber to the No Charge position by

means of the zeroing knob on the right side of the instrument.

Notes

1. A thimble chamber should not be used for radiation of wavelengths above or below the wavelengths range for which this particular thimble chamber has been calibrated against a free-air chamber.

2. It is necessary for corrections to be made for temperature variations. A temperature correction chart or curve is usually supplied by the manufacturer for each instrument.

3. If moisture or other foreign material gets across the terminals of the chamber it will discharge or at least show a leakage. This may be remedied by cleaning with carbontetrachloride.

Minometer

The minometer consists of a string electrometer, an ionization chamber and an electrical charging circuit for charging the ionization chamber. The instrument is used in measuring small amounts of gamma or x-radiation. The ionization chamber is quite frequently carried in the technician's pocket to determine daily dose.

FIGURE 172. Victoreen minometer and extra chamber

The electrometer is calibrated to a known voltage which is read on the scale in roentgen units. The string visible on the scale when observed through the microscope is a suspended platinum wire. The scale is divided into two sections, one showing a full-scale deflection at .1 r and the other at .01 r.

The ionization chamber acts as a condenser which, when inserted in the electrometer, is charged to a definite voltage. It is then removed and upon exposure to x-rays the ionization of the air within the chamber causes the voltage to leak off. When reinserted in the electrometer the voltage change is indicated on the scale in roentgens.

Because of the extreme sensitivity of the instrument a leak may occur if moisture, dirt or a fiber particle gets into the screw cap; the chamber will discharge entirely if the center pin is touched. A leaky chamber may sometimes be cleaned sufficiently by washing the contact end in carbon tetrachloride. As the purpose of the electrometer is only to measure the voltage change, any slight leak in it after the chamber is charged may be adjusted by recharging the electrometer to the "O" position before the chamber is reinserted.

The charging circuit consists of a toggle switch for turning the instrument ON or OFF, a filament transformer, a 6H6 tube, filter condensers and resistors, balancing resistors and a potentiometer, the adjustable tap of which supplies one side of the line to the ionization chamber and electroscope.

Operation

Plug the line cord into a 110 volt A.C. source and snap the toggle switch at the right side of the electrometer. Allow at least 30 seconds for the instrument to warm up before charging. Unscrew the knurled end of the chamber and insert the open end into the socket of the electrometer far enough to make contact. Then press in on the button above the toggle switch and at the same time turn the knob on the left until the string comes to the "O" position on the scale. This knob may be turned in either direction depending upon the location of the string when first observed. Release the charge button; then remove the chamber and screw on the knurled cap just removed. The chamber is now ready for making the radiation measurement.

To measure the radiation after the chamber has been exposed—before inserting the chamber check the position of the string in the electrometer to be sure it is on the "O" position

and, if not, adjust it as described above until it is. Then unscrew the threaded cap of the chamber and reinsert the open end into the socket of the electrometer until it makes contact. The deflection of string from the "O" position then indicates directly in roentgens the amount of radiation to which the chamber has been exposed.

Notes

The normal leak in the chamber should not exceed 1 minor division in 8 hours.

To adjust for the "Z" position press in the charging button and turn the charge adjustment knob in a clockwise manner as far as it will go. That should return the string to the "Z" position. If it does not the "Z" adjustment screw should be turned until the string is on "Z".

If the Minometer requires focusing, loosen the focus adjustment screw and move the sight tube slightly up or down until the image of the string becomes sharp. Then tighten screw.

If the minometer chamber indicates full scale deflection in less than one minute on any intensity of x-radiation, the accuracy is impaired. Exposures of less than one minute are not recommended.

Milliroentgen Meter

This instrument consists of a battery, ionization chamber, amplifying system, meter and control devices mounted in a single carrying case. The meter reads directly in milliroentgens per minute.

The battery is a 45 volt "B" battery (Burgess 2308, 8″ x 7″ x 3″) and supplies the instrument through a rheostat and OFF and ON switch.

The ionization chamber and amplifying system are mounted in a single cardboard tube which plugs into the bottom of the meter and control section. The ionization chamber is composed of a central wire and a metal lining in the cardboard tube. The amplifying system is composed of QW-1, QV-270 and TP-591 miniature tubes with the necessary resistors.

The meter is a direct current meter calibrated to read in milliroentgens per minute. The control box, in addition to containing the meter, contains a combination ON and OFF switch, potentiometer, and a selector switch indicating TEST, SET, and RUN. The rheostat in series with the supply battery is mounted on the right side of the carrying case.

FIGURE 173. Victoreen ionometer or milliroentgen meter

Operation

1. Open the covers over the ionization chamber and control sections.
2. Turn lower left combination switch and potentiometer ON and adjust the series rheostat to obtain a 40 volt reading on the meter with the selector switch set on TEST.
3. Turn the lower left selector switch to the SET position and ZERO the meter by adjusting the lower left potentiometer.
4. Turn the selector switch to the RUN position. The meter should ZERO when no radiation is present, but if there is some present the meter will indicate its amount in milliroentgens per minute up to 2 milliroentgens per minute.
5. In securing the meter the selector switch should be turned to the TEST position and the combination ON and OFF switch and potentiometer turned to the OFF position.

Notes

In order to obtain accurate measurements it is necessary to check the ZERO position of the meter on RUN. This entails the checking of the meter in the presence of NO radiation.

Normally there should be very little if any

drift of the meter but if there is a very noticeable amount it may mean that the battery is worn out or that there is something wrong in the amplifying circuit.

The instrument must be turned OFF after use in order to preserve the battery.

It is important that the cover around the ionization chamber be opened before use, especially in measuring low kilovoltage or stray radiation.

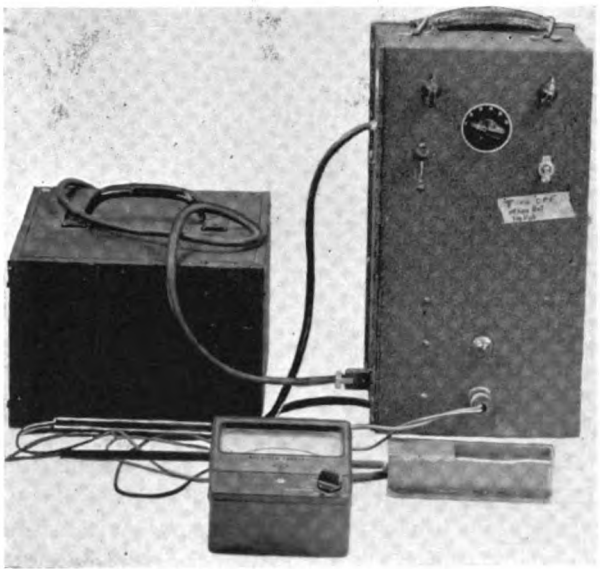


FIGURE 174. Naval Research Laboratory exposure meter

Geiger Counter

The Geiger Counter used by the Navy and called Radiography Exposure Meter consists of a control cabinet, battery supply box and Geiger counter tube. The instrument can be operated either from the batteries or from any 110 volt A.C. source.

The control cabinet contains the mini-max batteries for obtaining the high voltage supply to the Geiger tube, the rectifier tube, the 6G6 amplifier tubes supplying the bridge circuit, the micro-ammeter plug and all the necessary controls.

On the face of the instrument are several controls. The one of the lower left (A) is a double-throw switch which when in the upper position supplies the instrument from the 110 volt A.C. source and when in the lower position supplies it from the batteries. The upper left (B) control is a potentiometer in the bridge circuit which shunts the meter and is used for "zeroing" the meter. The upper right (C) control is a potentiometer across the last two batteries in the high voltage Geiger Tube Supply and is used for varying the sensitivity of the tube. An increase in voltage across the tube increases its sensitivity. The lower right (D) control is a double-throw switch, which, when in the upper position, places the high voltage supply across the Geiger Tube and in the lower position places the 90 volt supply across it. The center (E) selector switch has six different positions, the number 1 and 6 being paralelled. Each of these positions place different parallel combinations of resistors and condensers in series with the Geiger Tube to obtain different ranges of sensitivities. These combinations in addition to giving different ranges of sensitivities smooth out the Geiger Tube discharge ripples and convey the lowered voltage across the resistors to the grid of one of the 6G6 amplifying tubes. On the bottom of the instrument is a standard telephone jack plug into which the meter is plugged. Above the plug is a pilot lamp which lights when the double-throw instrument supply switch is thrown either up or down.

The battery box contains two 45 volt batteries in series which supply the plate voltage for the 6G6 tubes and two 3 volt batteries in series which supply the tube filaments.

The Geiger tube consists of a cathode, which is a chrome iron cylinder, 1 cm. in diameter and 3 cm. long, sealed directly to soft glass. The anode is an 8 mil tungsten wire supported from end on a standard metal stem. The stem end of the tube is cemented to a miniature four-prong coil form. A grounded cylinder of wire gauze surrounds the cathode. The entire assembly slips into a protective bakelite tube. The threshold of the tube is in the neighborhood of 800 volts.

The operation of the Geiger Tube is such that when the radiation enters the chamber it produces ions by collisions with the atoms of the gas within the chamber. These ions are accelerated by the voltage across the electrodes and produce other ions by collision. The re-

sults are an electrical discharge between the two electrodes and the consequent flow of current through the external resistance. The flow of current through the resistance produces a voltage drop across the resistance and reduces the voltage between the electrodes. This reduction of voltage interrupts the discharge within the chamber and stops the flow of current through the resistance. The duration of this pulse of current depends upon the magnitude of the resistance, the voltage and the structure of the Geiger Tube. During the interval when the tube is discharging, there is a voltage drop across the resistor. Therefore if the resistor is connected to the grid of an amplifying tube a pulse of current in the plate circuit will be caused by a discharge of the Geiger Tube. This pulse may be lead to a counting device or meter. The accuracy of this system of measuring radiation is reduced if the amount of radiation is large.

Operation

1. Connect all the different parts of the instrument with the proper leads.

2. Make sure the sensitivity selector (E) is set to the least sensitive scale (#6), the high voltage Geiger Tube supply switch (D) is the lower position, the bridge potentiometer (B) is in the central position and the high voltage tube supply potentiometer (C) is in the low position.

3. Turn the instrument supply switch (A) to either battery or A.C. and allow a few minutes for the vacuum tubes to warm up.

4. Set Geiger Tube in the proper place to measure the radiation. Turn the high voltage Geiger Tube supply switch (D) to the upper position.

5. Adjust the meter to the "zero" position by means of the potentiometer in the bridge circuit (B) ; i.e., the upper left control.

6. Check operation of the instrument by taking the meter with the long lead to the x-ray control panel and starting the x-ray. If a full-scale meter reading is not obtained, the sensitivity will have to be increased by either changing the range by means of the selector switch or for a small change by changing the position of the high voltage Geiger Tube supply potentiometer (C) to increase the voltage. To check the operation by means of a radium paint source the selector (E) should be set to the number 1 position of greatest sensitivity and the potentiometer (C) to the position of maximum voltage and the meter "zeroed" by means of the upper left potentiometer (B). The paint source should be brought to the Geiger Tube and any meter defection noted. If this latter test is used the sensitivity selector (E) should be set to a position of lesser sensitivity and the meter again "zeroed" before exposing the counter tube to the x-ray source. It is advisable to secure the high voltage supply (D) to the counter tube when changing ranges of sensitivity.

7. In securing the instrument it is necessary to bring the instrument supply switch (A) to the central position and bring the high voltage Geiger Tube supply switch (D) to the lower position.

Uses

1. The instrument was originally designed as an exposure meter for radium and as such is used in the following ways:

(a) By placing the Geiger Tube behind the object to be radiographed and checking the reading of the microammeter; then move the instrument back until the meter reading is the same with no absorber between the Geiger tube and the radium source. The exposure time for the object would be the same as that for a film placed at the greater distance with no absorber.

(b) Set the instrument so that it reads a certain amount at a standard distance; then place the counter tube behind the object and check the meter reading. The proper exposure time may be obtained from curves drawn to show the proper exposure time at any meter reading.

2. The instrument may be used for measuring absorptions of any material providing the radiation is of 100 Kv.P. or higher. The instrument does not indicate accurate percentages of transmission; therefore, in making absorption tests, corrections will have to be made to the readings. Figure 13090 is a graph of percentages of transmission at 400 Kv.P. plotted against thickness of copper in millimeters with two curves showing the readings of the Geiger counter and a Condenser R-meter. The cor-

rection to the Geiger counter reading may be obtained from these two curves.

Notes

1. When the instrument is not in use the high voltage switch (D) to the counter tube should be turned to the lower position to prevent discharging the two batteries in parallel with the potentiometer.
2. The instrument is subject to a large "zero" drift if the filament or other batteries become worn out.
3. Any moisture or dirt particles across the counter tube or socket will cause the meter to read high and if too bad it will be impossible to "zero" it. This can be remedied at least partially by cleaning with carbon tetrachloride or by blowing out with warm dry air.
4. The counter tube is sensitive to temperature changes. If the temperature is too high, it will be impossible to "zero" the meter.

Ansco-Sweet Densitometer Model 11

This densitometer is of the single range, photo-tube type, and measures the diffuse density of the film. For the purpose of description the instrument is divided into the electrical and optical systems.

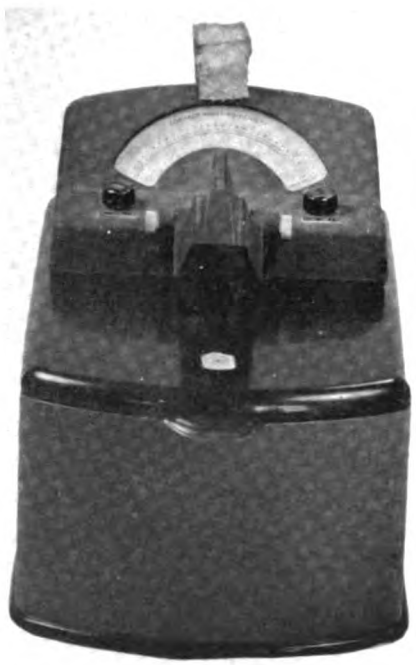


FIGURE 175. Ansco-Sweet photoelectric densitometer

The optical system is quite simple. The variable light source is a 15-C.P. concentrated-filament auto headlamp which is focused by a single condenser on the aperture. A heat-absorbing filter is used to eliminate the infrared radiation. The sample to be measured is placed immediately over the aperture which is located in the base plate of the instrument. After passing through the sample, the beam is absorbed by the phototube. From this it can be seen that the system is of the double-diffuse type since the sample is diffusely illuminated and the emergent light is diffusely received.

The electrical system consists of a voltage regulator in the 115-V A.C. supply line, an instrument power supply unit which consists of a transformer, an 80 tube, filter condenser, and a series resistors, a 1 M.A. meter with a scale reading from 0 to 3 and photo-tube head which contains a 929 photo-tube and a 6F5 triode amplifier tube, the output of which supplies the meter.

See Figure 176 for a wiring diagram of this instrument.

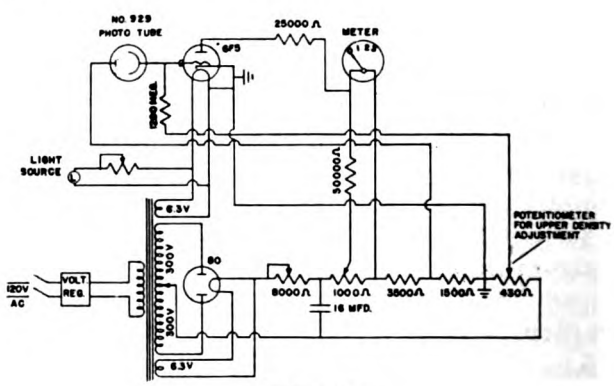


FIGURE 176

Operation

1. Plug cord into a 115-V A.C. 60 cycle supply and turn on switch.
2. Allow the instrument to heat up for about 1 minute; then bring the arm all the way down and adjust the pointer to the Zero position by means of the rheostat in series with the light source.
3. Select a step on the step-wedge that has

a density of nearly 3.0. Place this step over the light source aperture and bring the arm all the way down again. Check the meter reading and if it does not correspond to the density of the standard wedge, adjust it by turning the knob of the potentiometer located on the under left-hand side of the instrument top.

4. Occasionally check the whole range of steps on the standard wedge to determine whether or not the instrument is giving a true reading over its entire range. If the instrument does not follow correctly it can usually be remedied by changing the grid bias voltage.

5. After the instrument is properly adjusted the film density may be measured by placing the area of the film to be measured over the aperture and the arm brought all the way down. The film density may then be read directly from the meter.

Notes

1. The instrument is not very sensitive to small voltage fluctuations but it is quite sensitive to frequency changes. If there has been a frequency change, it will be necessary to recalibrate the instrument in order to obtain accurate measurements.

2. The arm must be all the way down when making measurements in order to avoid errors.

3. Do not allow the arm to be thrown back against the meter face by the spring. The force of the arm hitting the meter face could injure the meter or the tubes in the arm.

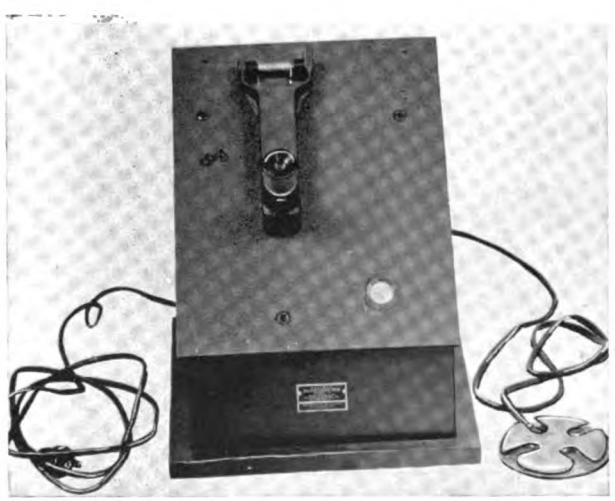


FIGURE 177. Capstaff-Purdy densitometer or density comparator

Eastman Transmission Densitometer

The Eastman Densitometer is a comparator type designed to measure diffuse densities from 0 to 3.0 of circular areas of 0.5 mm. diameter.

The essential elements of the instrument shown on the schematic diagram are as follows: a light source A both for illuminating at H the density to be measured and for furnishing the comparison beam; a photometric field at G obtained by the aid of the mirrors B, D, F, and G; a photographic wedge W for decreasing by a known amount the intensity of the light illuminating the density; and an eyepiece J for viewing the photometric field.

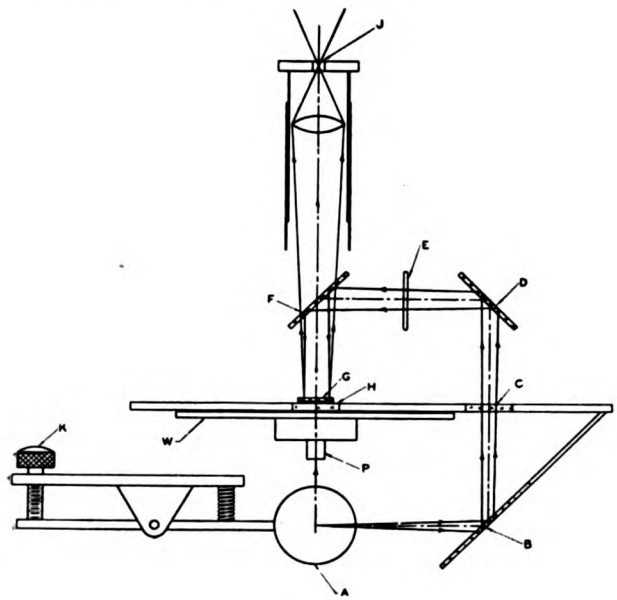
The light source A is a 5-volt, 4-ampere, 32-candle power automobile headlight lamp and in order to permit the use of 110-volt, A.C. line, a small transformer is introduced into the circuit. One beam of light from the lamp passes through the circular wedge W which rotates on the pin P. To facilitate turning, the wedge projects from under the instrument cover.

The beam of light after passing through the wedge falls upon the opal glass H which acts as a diffusing screen upon which the film to be measured is laid. The opal glass also acts as an illuminator for the detection of the spot to be measured.

A second beam of light coming from the lamp is led around by the two mirrors, B and D, to the photometric head which consists of a plane glass F set at an angle of 45 degrees, so arranged that the light from the mirror system is reflected to the base of the head. The two surfaces of the plane glass reflect sufficient light (about 10%) to furnish the comparison beam. In order to insure a uniform patch of light, a piece of opal glass C is placed between the mirrors B and D and a piece of ground glass E between D and F. In the base of the head is a circular plane silver mirror G with its reflecting surface away from the opal glass H and in the center of the mirror the silver is removed over an area of 0.5 mm. in diameter. The observer sees in the eyepiece J a small

round spot illuminated by the opal glass H surrounded by a comparison field illuminated from the mirrors B, D, and F.

In order to make the dividing line in the photometric field become entirely invisible when the two parts of the field are balanced, the mirror G is thinly silvered and thinly varnished. The silver surface is protected from the atmosphere and from scratching by cementing with Canada Balsam a micro-cover glass onto the mirror. In order to prevent scattered light from entering the photometric field when a small dense spot is surrounded by a large light area, and also to act as a bumper, a thin sheet of dull black paper is pasted over the cover glass. A hole slightly larger than the hole in the silver surface of the mirror is cut in the center of the black paper.



SCHEMATIC DIAGRAM OF EASTMAN DENSITOMETER

FIGURE 178

Operation

1. Connect the plug to a 115 volt A.C. 60-cycle line.

2. Depress foot switch and adjust the focus by turning the eyepiece until the spot in the center of the field is in sharp focus.

3. Establish the photometric balance by rotating the wedge with the projection. If, when the balanced field is obtained, the zero mark on the wedge is not exactly under the hairline, adjust the position of the lamp by turning the knurled disc until balance is found with the zero under the hairline.

4. Raise the arm piece and place the spot of the film where the density is to be measured over the target on the opal glass immediately below the eyepiece and bring the arm down in contact with the film.

5. Re-establish the photometric balance by rotating the wedge; the density of the spot being measured is given under the hairline.

Notes

1. Do not leave the lamp on when the instrument is not in use since heat from the lamp over a long period of time will damage the wedge.

2. Avoid fingering the wedge as dirt on it will render the results incorrect.

3. The instrument can be read with greater ease and accuracy in a dimly lighted room.

4. Because both beams of light originate from the same source, variations in line voltage do not affect the accuracy of the instrument.

Focal Spot Size Camera

Two instruments used to measured the focal spot size of an x-ray tube target are a pin hole camera and a spot size camera. The pin hole camera is used for low voltage machines where the radiation is easily absorbed by a relatively thin sheet of lead. A lead plate containing a pin hole (not over .020 in diameter) in the

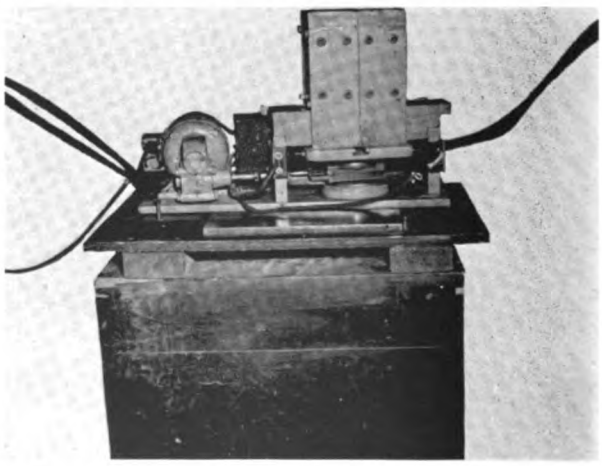


FIGURE 179. The Sperduto 2 M.E.V. spot size camera

center is interposed approximately midway between the x-ray tube target and the film. A smaller hole will produce a more sharply defined spot image, but will require a longer exposure time. From the image size and the distances, the spot size may be easily calculated.

Using the spot size camera, one must scan the target with a lead block of suitable thickness having a small slit approximately .003 inch wide.

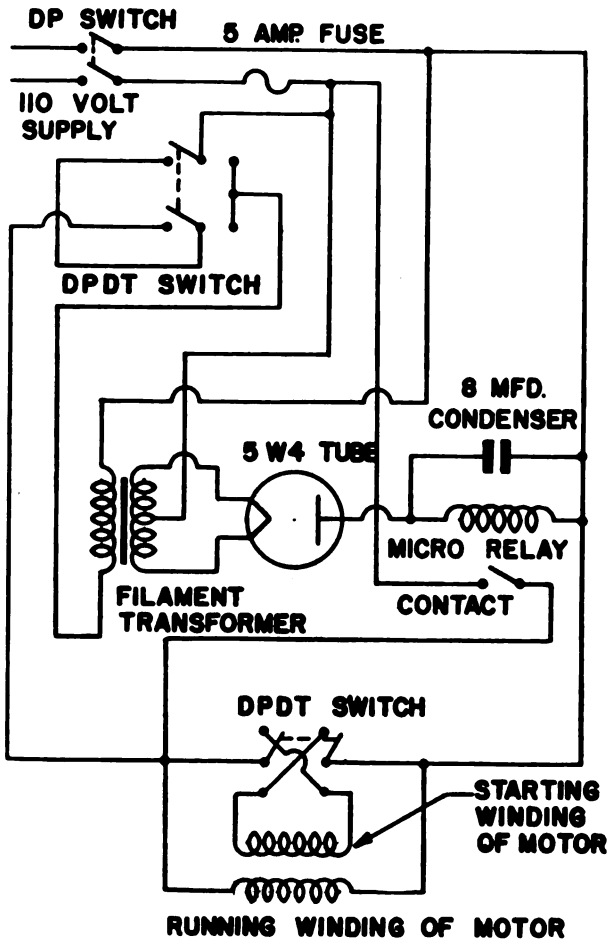


FIGURE 180

A device using this principle is shown in Figure 179. The circuit shown is shown in Figure 180. There are two lead blocks reinforced with ¼" steel plates on each side and separated from each other by .003". These blocks are moved back and forth by a reversible motor and gear reduction. This oscillation allows the block to scan the area beneath the target twice a minute. The film is placed in the slot beneath the blocks.

To measure the focal spot size of the Van de Graaff generator, raise the camera until it is 18" from the target. Dental film is placed in the holder and the 110 volt lead plugged into supply. The exposure time is 200 seconds 1.5 feet, 2 M.E.V., 300 ua.

To obtain the spot size, place the film on the viewer and measure the width very carefully. The focal spot equals the width of line minus twice the shim thickness. If two measurements are made 90° apart, they should be equal and the spot is round.

Spot Location—The position of the focal spot can be found by this method if the film and camera are centered very carefully and the measurements correlated with the position of the line on the film.

Another method of locating the spot is to suspend two brass balls by means of a string from the center of the target so that the first ball is 6' and the second ball 12" from the target.

A film is exposed for 200 seconds, 300 ua, 2 MEV, in contact with lower ball. The focal spot will be off center by the distance between ball centers and in the opposite direction. Always square film with building so that results can be correlated. This distance should never be more than ¼ of an inch. The spot can be centered by tightening bolts on tube flange or shortening target.

Chapter 23

THE GEIGER COUNTER X-RAY SPECTROMETER

According to Braggs law a crystalline substance exposed to a fine beam of monochromatic X-radiation will emit a series of beam maxima whose angular divergence and intensities are characteristic of that substance. Inasmuch as the spacings and intensities of these maxima are dependent upon the spacing between the atomic planes of the substance their study provides not only useful information relative to ultimate structure but affords also an excellent means of identification or differentiation.

The Geiger Counter X-Ray Spectrometer is an instrument used to focus a monochromatic X-Ray beam on a specimen of powder and a Geiger Counter tube with circuit and recorder to read the reflected intensities and angular divergence.

Any crystalline substance can be analyzed by this method in about 45 minutes by use of the d spacings obtained and the ASTM Hanawalt Tables.

Specimen Preparation

Three methods of preparation are available. In all cases the sample should be powdered. For this a mortar and pestle will be most useful.

The sample may be dusted into a ½ inch hole in a glass slide, one face of which is covered by a thin film (about 0.001 inch) of plastic to maintain a plane surface, the rear face by a solid glass slide. In this laboratory, the film used is the cellophane from the outside of a cigarette package. In attaching the film and in cementing the two glasses together use a minimum of cement and only around the outer edge of the glass. Pressing together will spread it sufficiently. In preparing, pour the material in the cavity and level off with a razor blade without packing. The film slide faces the x-ray beam.

In the second method, the sample is mixed with a binder (collodion, adhesive cement, magnesium oxide, etc.) and spread with one pass as a smear on the surface on a glass slide. Allow to dry five or ten minutes; do not touch the front surface.

Lastly, spread a thin layer of a binder on the glass and while still tacky, sprinkle the powdered sample thereon. Do not touch the powdered surface.

For permanent samples the first method is the best although it requires the longest preparation time. It also gives samples with a minimum of particle orientation. The third method also gives little preferred orientation and may be used satisfactorily for temporary samples.

Metal samples may be analyzed by electrolytically cleaning the surface and exposing a reasonably smooth face of a solid sample.

FIGURE 181

Slit System

For most operations the slits on the x-ray head are left at their maximum openings, and those at the Geiger tube opening are also at maximum. In checking, however, it is well to sweep the Geiger tube over its arc by hand, noting the maximum peak and if necessary cut down the x-ray tube slits to keep the pen on the paper.

The Spectrometer consists of three parts—x-ray machine, counter and recorder.

The x-ray transformer and tube are mounted independently. The tube has a flat anode; radiation is emitted from two ports. The port supplying the Geiger Counter is covered by slit and a shutter which protects the operator when adjusting the sample in the holder.

The Geiger Counter circuit is mounted in a separate cabinet. The counting circuit is used to record the intensities of the reflected radiation. This circuit is adjusted before readings are begun. The motor mounted on the counter tube moves the tube around the arc at the rate of 2 degrees per minute.

The Recorder, connected in the counter circuit is an Esterline-Angus recording milliammeter.

Operation

The entire installation is operated from an ordinary 115 volt A.C. outlet, with the third wire connected to ground. The outlet should be capable of supplying one KVA.

At start all switches are off, the x-ray flag or shutter up, and the motor not attached. Turn on the x-ray main switch and the counter main switch. When the counter voltmeter indicates

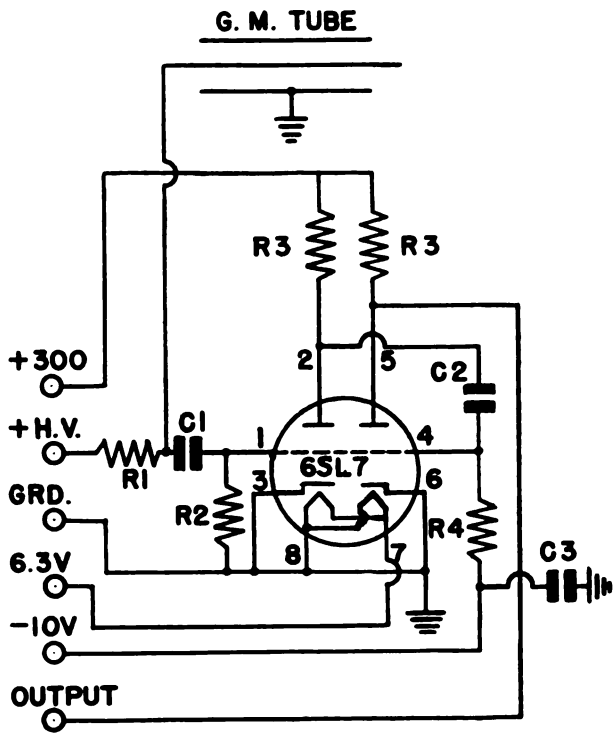


FIGURE 182. Schematic Wiring Diagram, G. M. Tube

1400 volts on the Geiger tube turn on the x-ray contactor. Slide the Goniometer to the upper end of its travel or to a point a part of a degree past the desired starting point. Align the paper in the recorder with one of the cross lines. Mark the paper with the sample's data and the starting angle. Lower the x-ray flag, attach the driving motor. When the motor brings the indicator to zero at the desired angle, turn on the recorder switch. At the end of the run the motor will be shut off when its switch strikes the stop which can be placed at any desired point. Raise the x-ray flag and remove the motor. It has been found helpful to use an interval timer clock to give an audial indication of the finishing of the run, set in minutes at the angle to run divided by two. To prevent damage to the meters and to give silent running, leave the METER switch at VOLTS and the TIMER switch at RESET.

Notes

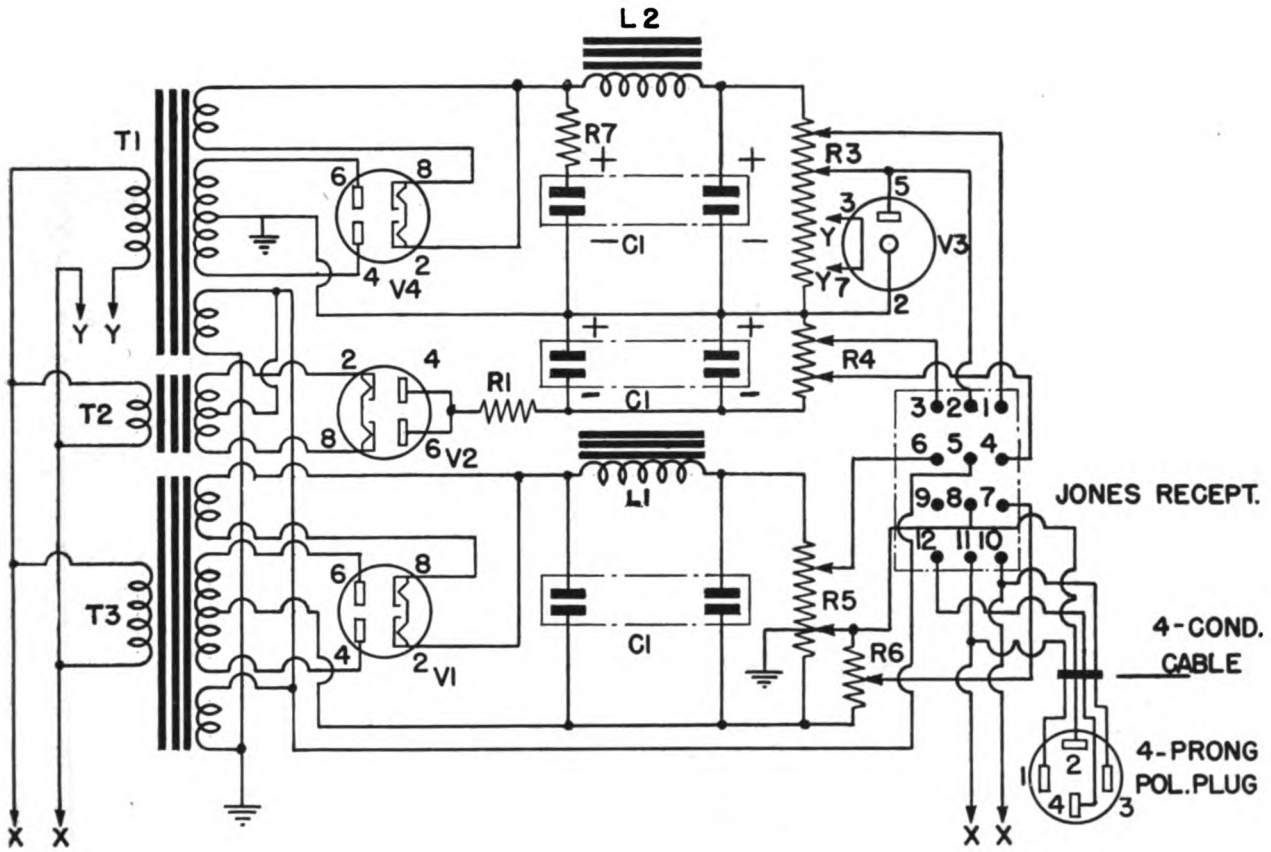
In order to obtain maximum peaks on the frequency meter the 6SJ7 tube has been replaced with a 6AC7, if slightly greater gain is required a 6AG7 tube may be used. The change involves mere interchange of the tubes as the base diagrams are essentially the same. Also the plate and grid resistors have been changed from 39,000 OHMS each to 10,000 OHMS and 20,000 OHMS respectively.

After the reflected intensities and positions are determined from the recording tape, then the d spacing can be calculated from the table indicated below. The tracings given by each substance acts as its identification signature. By using the Hanawalt Tables the substance can be identified. There are three cards for each substance.

1. Showing strongest line first.
2. Showing middle line first.
3. Showing weakest line first.

When a known substance has been identified with a tracing from the spectrometer that tracing can be used as a master trace to identify all other samples that show the same pattern.

The circuits are shown to aid in using the spectrometer. Care should be exercised to avoid exposure to the direct beam.



CODE	PART NO.	REQ.	VALUE
R1	5197	1	5K 10 WATT
R3	5195	1	25K 80 WATT
R4	5199	1	50K 50 WATT
R5	5189	1	25K 50 WATT
R6	5170	1	50K POTENTIOM.
R7	6111	1	750 ~ 10 WATT
C1	5927	3	8-8 MFD. 450 V. ELECTROLYTIC

CODE	PART NO.	REQ.	VALUE
L1	5691	1	30H FILTER CHOKE
L2	5692	1	15H FILTER CHOKE
T1	5688	1	P'W'R. TRANSFORMER
T2	5690	1	FIL. TRANSFORMER
T3	5689	1	P'W'R TRANSFORMER
V1		1	5Z4
V2		1	5Z4
V3		1	VR 90/30
V4		1	5Z4

JONES RECEPT.

1	TO +300	7	TO — 20
2	" + 90	8	" GND
3	" — 15	9	"
4	" — 80	10	" 110 AC.
5	" 6.3 AC.	11	" 110 AC.
6	" +180	12	" V.M.

FIGURE 183. Schematic Wiring Diagram, Scaling Circuit Power Supply

699810—46—14

The x-ray transformer and tube are mounted independently. The tube has a flat anode; radiation is emitted from two ports. The port supplying the Geiger Counter is covered by slit and a shutter which protects the operator when adjusting the sample in the holder.

The Geiger Counter circuit is mounted in a separate cabinet. The counting circuit is used to record the intensities of the reflected radiation. This circuit is adjusted before readings are begun. The motor mounted on the counter tube moves the tube around the arc at the rate of 2 degrees per minute.

The Recorder, connected in the counter circuit is an Esterline-Angus recording milliammeter.

Operation

The entire installation is operated from an ordinary 115 volt A.C. outlet, with the third wire connected to ground. The outlet should be capable of supplying one KVA.

At start all switches are off, the x-ray flag or shutter up, and the motor not attached. Turn on the x-ray main switch and the counter main switch. When the counter voltmeter indicates 1400 volts on the Geiger tube turn on the x-ray contactor. Slide the Goniometer to the upper end of its travel or to a point a part of a degree past the desired starting point. Align the paper in the recorder with one of the cross lines. Mark the paper with the sample's data and the starting angle. Lower the x-ray flag, attach the driving motor. When the motor brings the indicator to zero at the desired angle, turn on the recorder switch. At the end of the run the motor will be shut off when its switch strikes the stop which can be placed at any desired point. Raise the x-ray flag and remove the motor. It has been found helpful to use an interval timer clock to give an audial indication of the finishing of the run, set in minutes at the angle to run divided by two. To prevent damage to the meters and to give silent running, leave the METER switch at VOLTS and the TIMER switch at RESET.

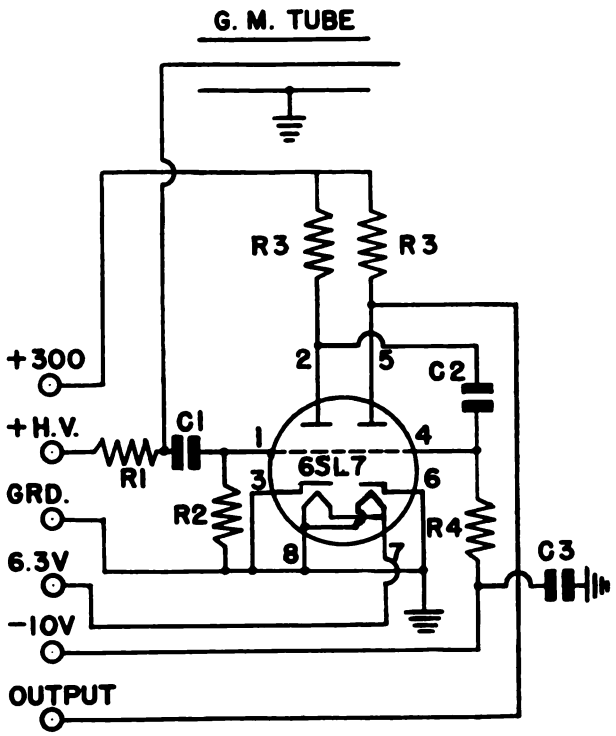


FIGURE 182. Schematic Wiring Diagram, G. M. Tube

Notes

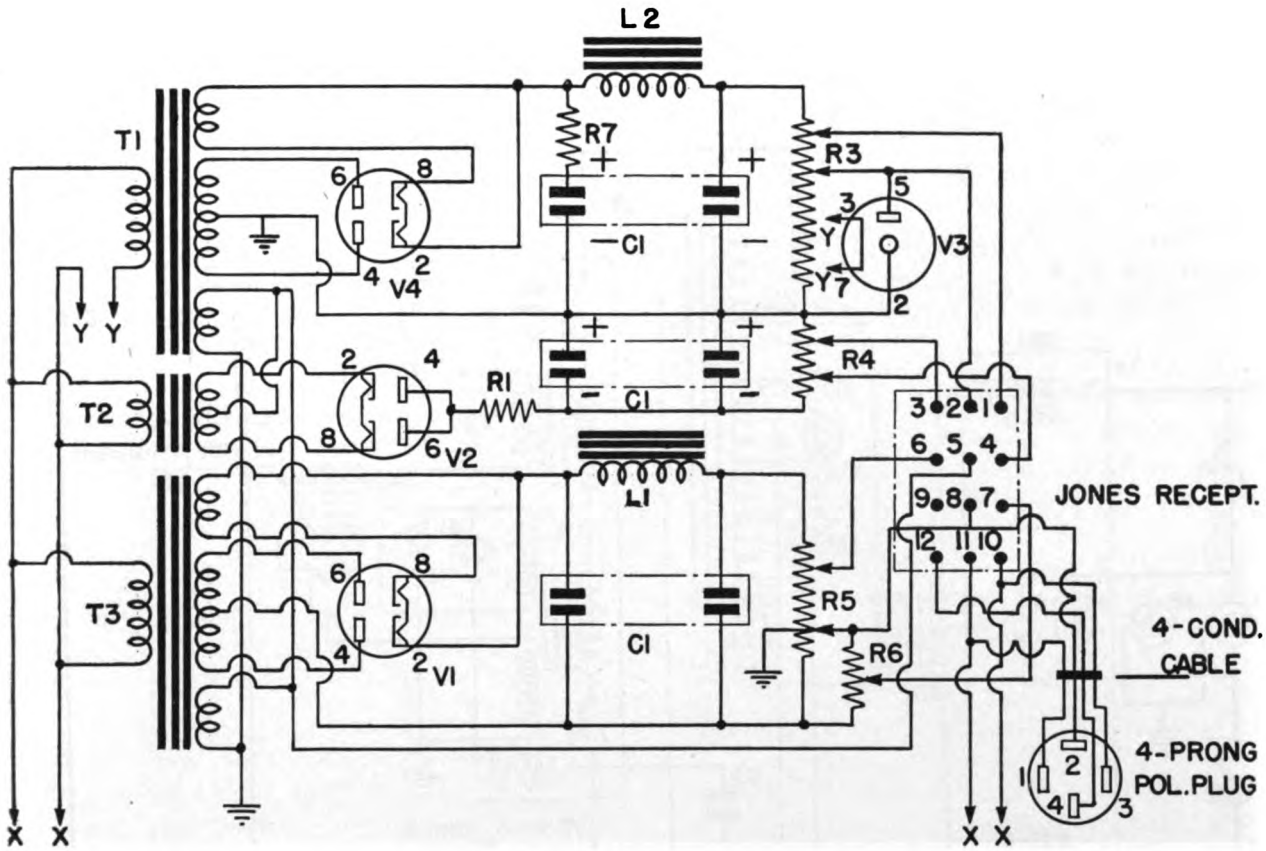
In order to obtain maximum peaks on the frequency meter the 6SJ7 tube has been replaced with a 6AC7, if slightly greater gain is required a 6AG7 tube may be used. The change involves mere interchange of the tubes as the base diagrams are essentially the same. Also the plate and grid resistors have been changed from 39,000 OHMS each to 10,000 OHMS and 20,000 OHMS respectively.

After the reflected intensities and positions are determined from the recording tape, then the d spacing can be calculated from the table indicated below. The tracings given by each substance acts as its identification signature. By using the Hanawalt Tables the substance can be identified. There are three cards for each substance.

1. Showing strongest line first.
2. Showing middle line first.
3. Showing weakest line first.

When a known substance has been identified with a tracing from the spectrometer that tracing can be used as a master trace to identify all other samples that show the same pattern.

The circuits are shown to aid in using the spectrometer. Care should be exercised to avoid exposure to the direct beam.



CODE	PART NO.	REQ.	VALUE
R1	5197	1	5K 10 WATT
R3	5195	1	25K 80 WATT
R4	5199	1	50K 50 WATT
R5	5189	1	25K 50 WATT
R6	5170	1	50K POTENTIOM.
R7	6111	1	750 ~ 10 WATT
C1	5927	3	8-8 MFD. 450 V. ELECTROLYTIC

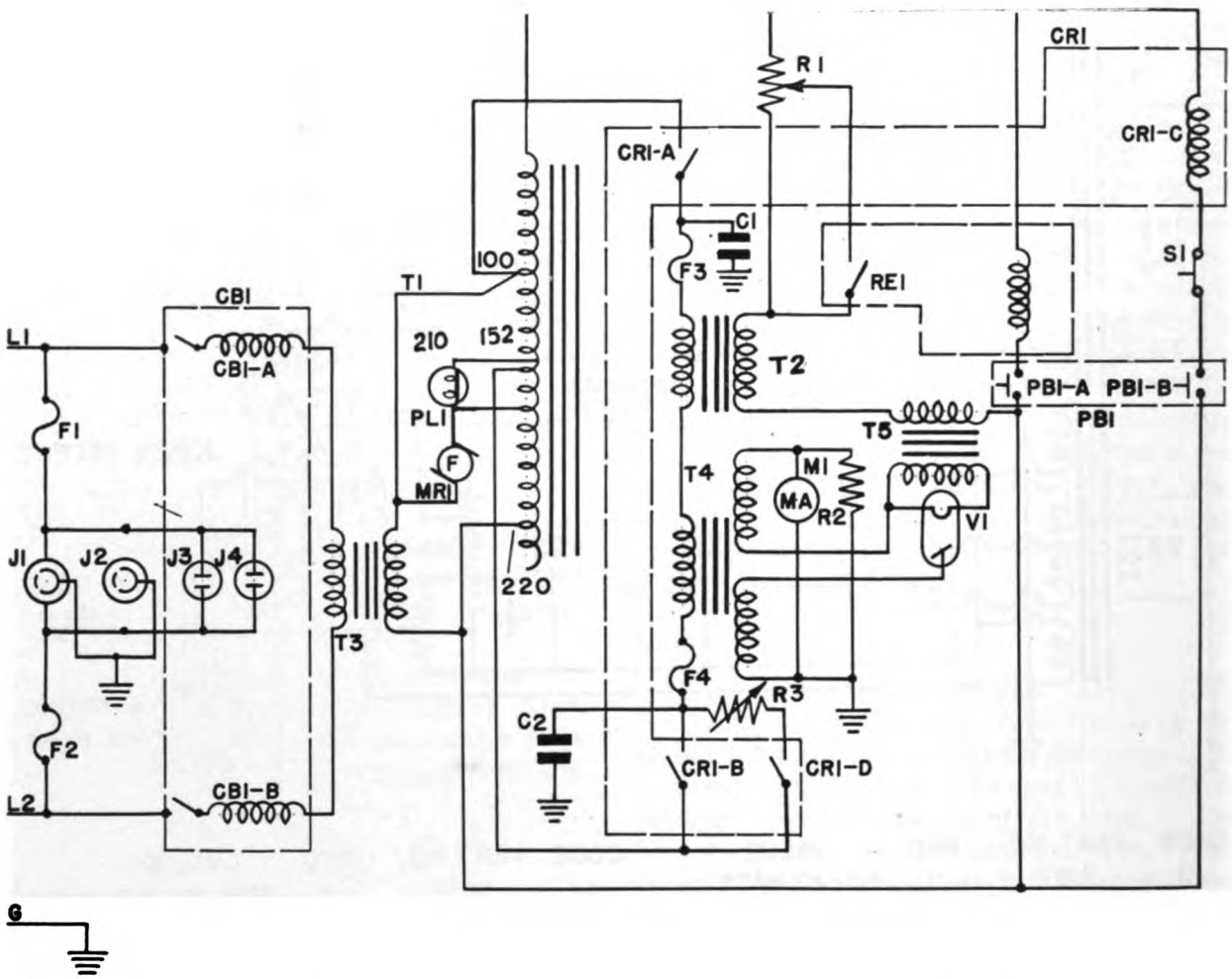
CODE	PART NO.	REQ.	VALUE
L1	5691	1	30H FILTER CHOKE
L2	5692	1	15H FILTER CHOKE
T1	5688	1	P'W'R. TRANSFORMER
T2	5690	1	FIL. TRANSFORMER
T3	5689	1	P'W'R TRANSFORMER
V1		1	5Z4
V2		1	5Z4
V3		1	VR 90/30
V4		1	5Z4

JONES RECEPT.

1	TO +300	7	TO — 20
2	" + 90	8	" GND
3	" — 15	9	"
4	" — 80	10	" 110 AC.
5	" 6.3 AC.	11	" 110 AC.
6	" +180	12	" V.M.

FIGURE 183. Schematic Wiring Diagram, Scaling Circuit Power Supply

699810—46—14



CB1	5076	CIRCUT BREAKER	C1	5400	CONDENSER
F1	5058	FUSE—10 A CARTRIDGE	C2	5400	CONDENSER
F2	↓	↓ ↓ ↓	CR1	5081	CONTACTOR
F3			PB1	5822	PUSH BUTTON
F4			S1	5818	INTERLOCK
J1	5464	RECEPTICLE	M1	5217	MILLIAMMETER
J2	5464	RECEPTICLE	MR1	6308	BLOWER MOTOR
PL1	5503	PILOT LIGHT	R1	5131	RESISTOR
T1	328188	AUTO—TRANSFORMER	R2	5113	RESISTOR
T2	6-38048	REACTOR	R3	5114	RESISTOR
T3	5560	STABILIZER	V1	32061 OR 62	X-RAY TUBE
T4	C-38086	H.T. TRANSFORMER	RE1	5003	RELAY
T5	C-38116	TUBE FILAMENT TRANSFORMER			

FIGURE 184. Schematic Wiring Diagram, Diffraction Spectrometer X-Ray Circuit

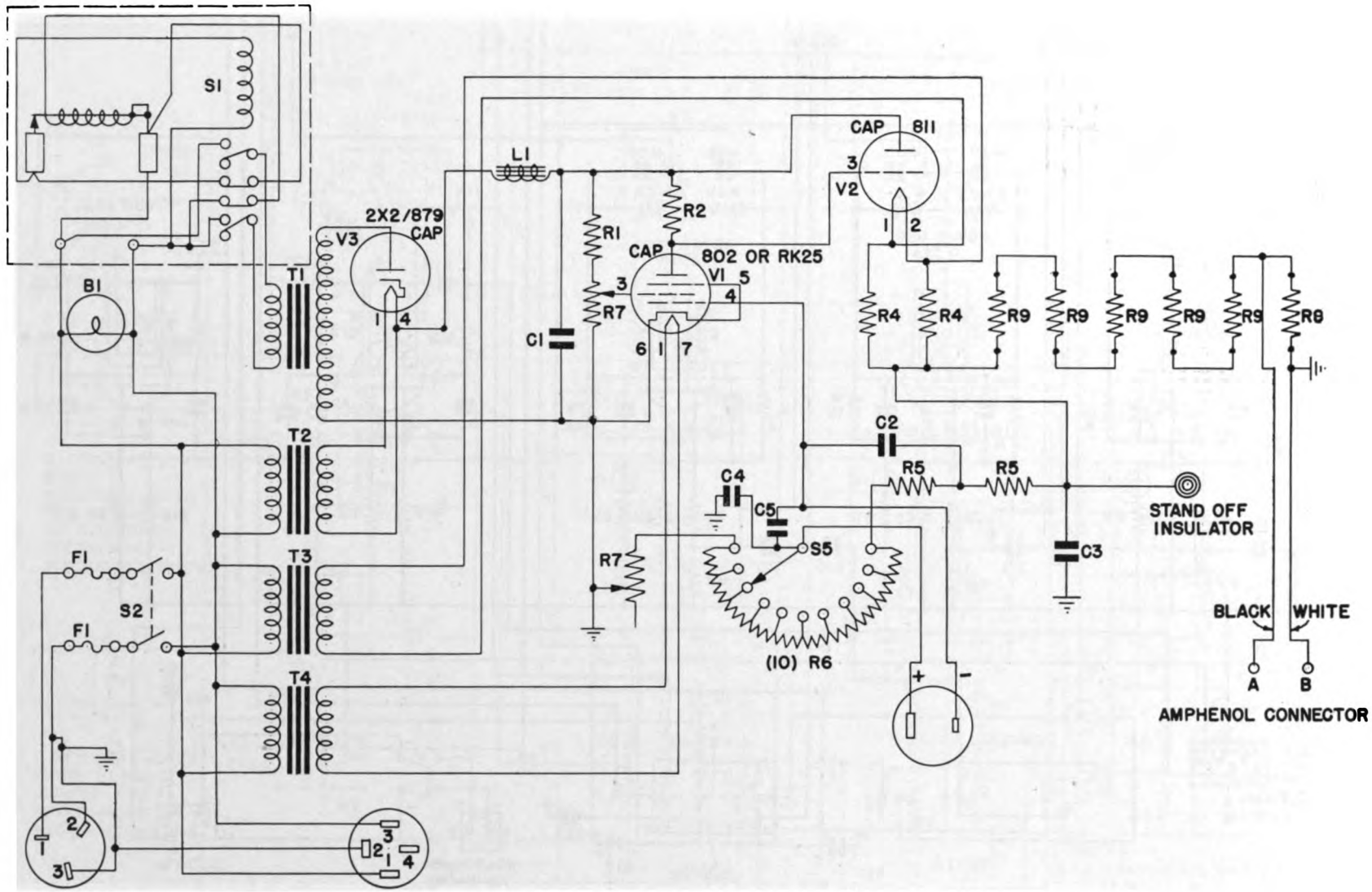


FIGURE 185. Schematic Wiring Diagram, G. M. Power Supply

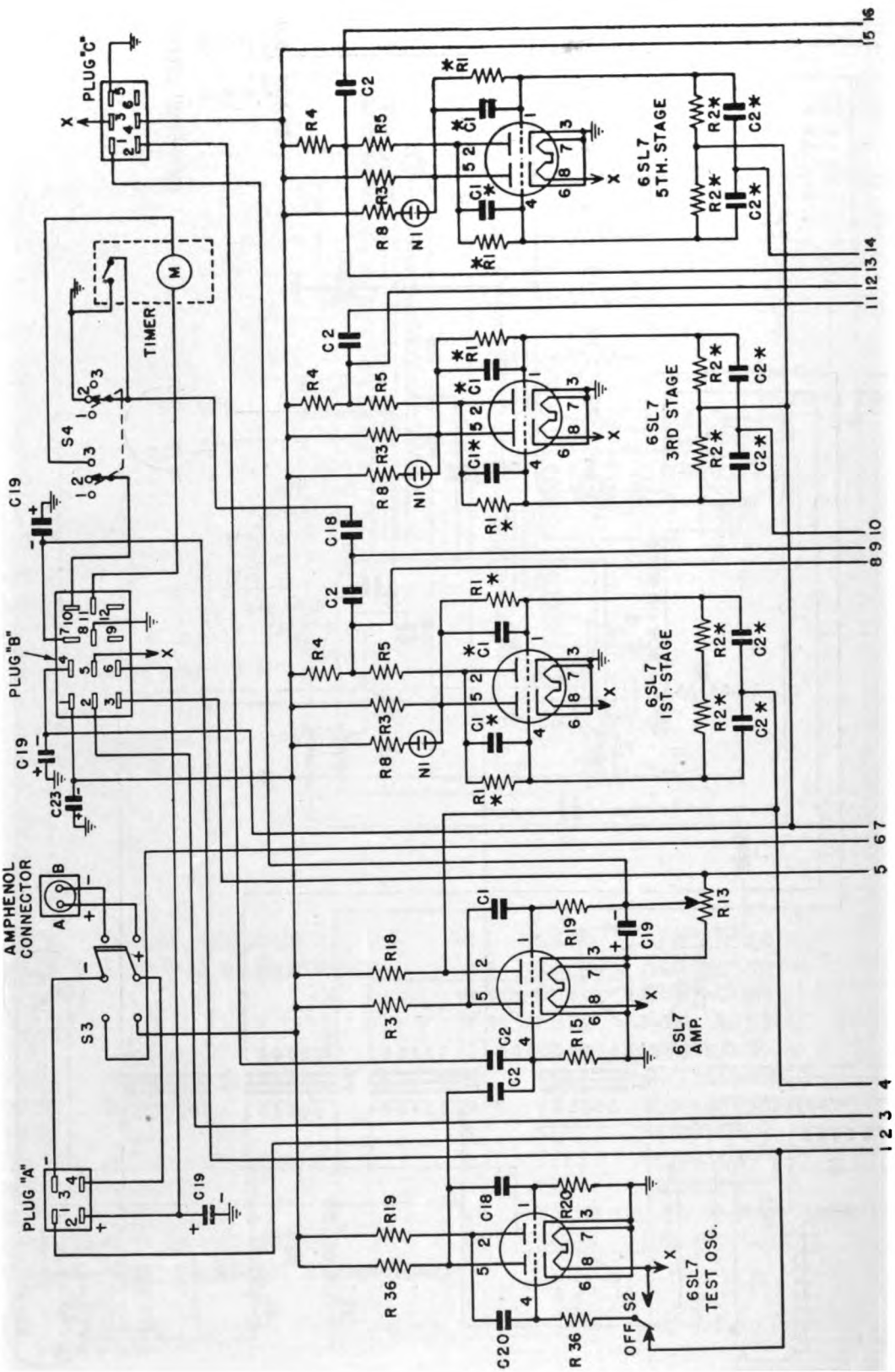
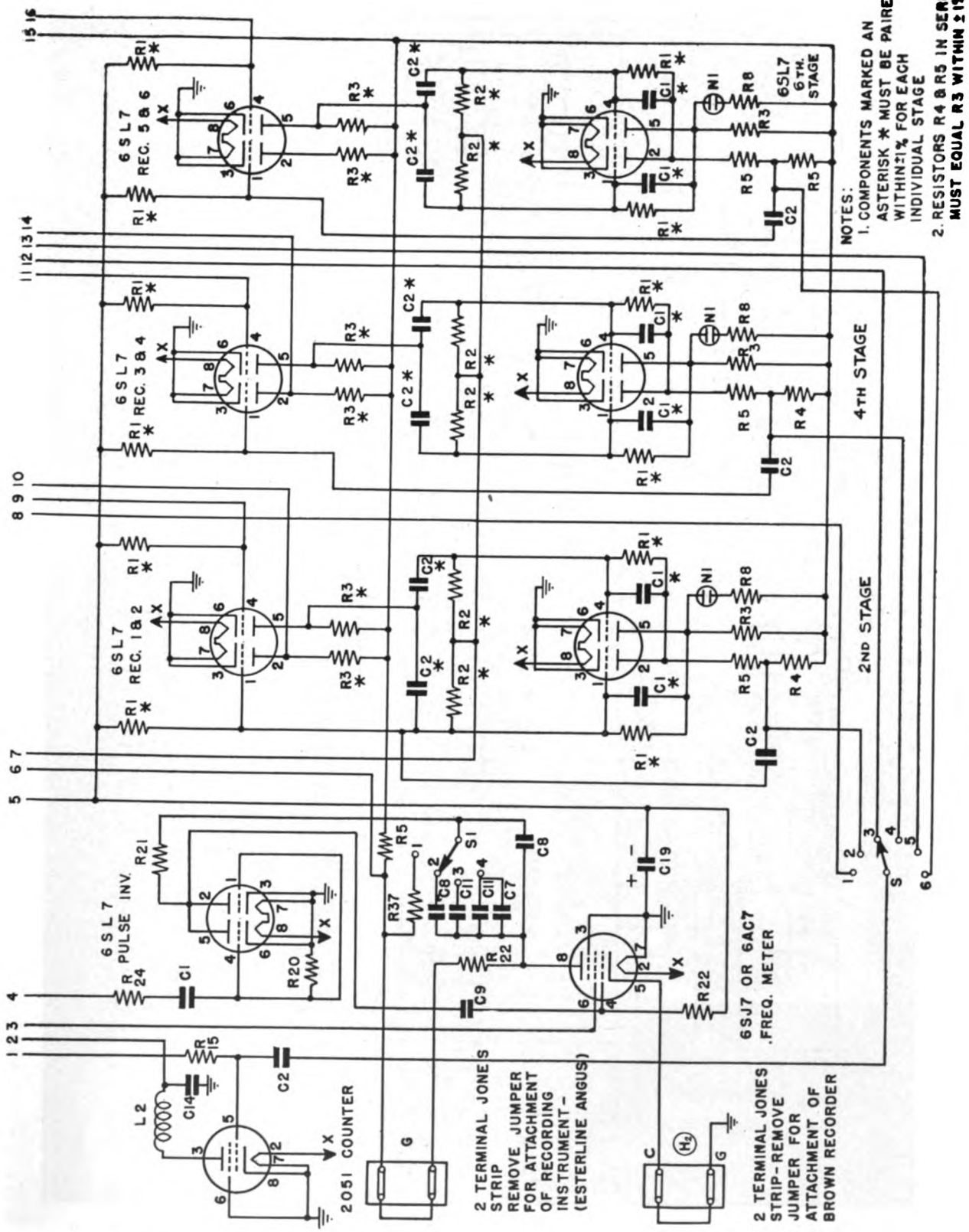


FIGURE 186. Schematic Wiring Diagram,


NOTES:
1. COMPONENTS MARKED AN ASTERISK * MUST BE PAIRED WITHIN ±1% FOR EACH INDIVIDUAL STAGE
2. RESISTORS R4 & R5 IN SERIES MUST EQUAL R3 WITHIN ±1%
6SL7 REC. 5 & 6
6SL7 REC. 3 & 4
6SL7 REC. 1 & 2
6SL7 PULSE INV.
6SL7 6TH. STAGE
4TH STAGE
2ND STAGE
6SJ7 OR 6AC7 .FREQ. METER
2051 COUNTER
2 TERMINAL JONES STRIP REMOVE JUMPER FOR ATTACHMENT OF RECORDING INSTRUMENT- (ESTERLINE ANGUS)
2 TERMINAL JONES STRIP-REMOVE JUMPER FOR ATTACHMENT OF BROWN RECORDER

Scaling Circuit for Diffraction Spectrometer

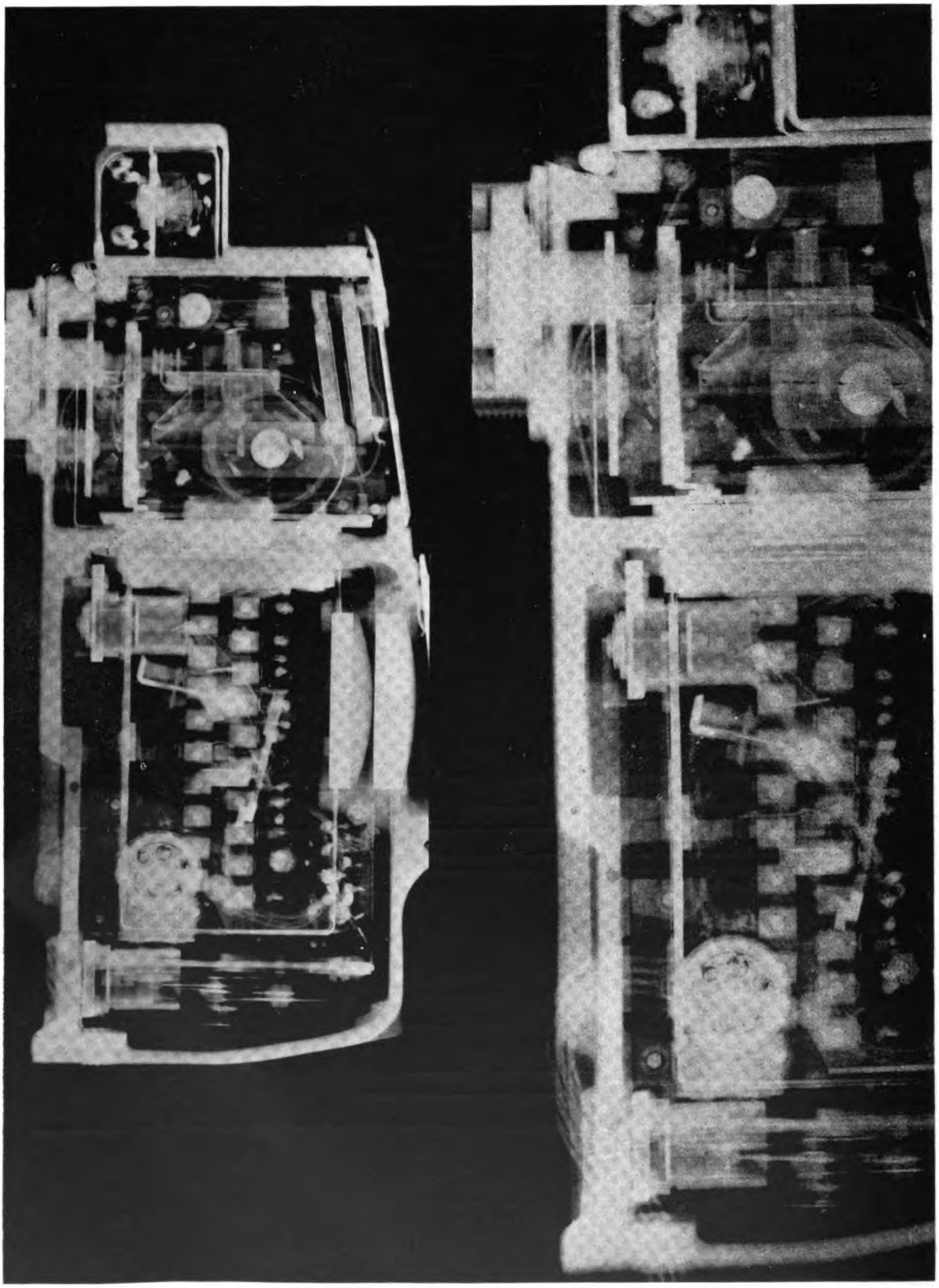


FIGURE 187. *Left:* radiograph on Type A film; *Right:* radiograph on Powers x-ray paper

TABLE XLI

X-Ray Spectrometer Conversion Table

Goniometer Angle to Interplanar Spacing

Column one — ϕ Goniometer angle
two — d Interplanar spacing
three — Difference
Center of sheet — Interpolation table

From Bragg's equation:

$$d \quad \frac{N\lambda}{2 \sin \theta}$$

d — Interplanar spacing in Angströms
N — An integer, this case - unity
λ — X-ray wavelength in Angströms
Copper target 1.539 A
θ — Reflection angle in degrees
equal to ½ ϕ
ϕ — Goniometer angle in degrees

ϕ	d										ϕ	d	
2.0	44.1				21	20	19	18	17		6.0	14.7	3
1	42.0	21									1	5	2
2	40.1	19	1	2	2	2	2	2			2	2	3
3	38.3	18	2	4	4	4	4	3			3	0	2
4	36.8	15	3	6	6	6	5	5			4	13.8	2
5	35.3	15	4	8	8	8	7	7			5	6	2
6	33.9	14	5	10	10	10	9	9			6	4	2
7	32.7	12	6	13	12	11	11	10			7	2	2
8	31.5	12	7	15	14	13	13	12			8	0	2
9	30.4	11	8	17	16	15	14	14			9	12.8	
			9	19	18	17	16	15					
3.0	29.4	10									7.0	12.60	20
1	28.4	10									1	43	17
2	27.6	8									2	25	18
3	26.7	9									3	09	16
4	25.9	8			16	15	14	13	12		4	11.92	17
5	2	7									5	77	15
6	24.5	7	1	2	2	1	1	1			6	61	16
7	23.8	6	2	3	3	3	3	2			7	46	15
8	2	6	3	5	4	4	4	4			8	31	15
9	22.6		4	6	6	6	5	5			9	17	14
		6	5	8	8	7	6	6					
4.0	22.0	5	6	10	9	8	8	7			8.0	11.03	14
1	21.5	5	7	11	10	10	9	8			1	10.89	14
2	0	5	8	13	12	11	10	10			2	76	13
3	20.5	5	9	14	14	13	12	11			3	63	13
4	0	4									4	51	12
5	19.6	4									5	38	13
6	2	4									6	26	12
7	18.8	4									7	14	12
8	4	4		11	9	8	7	6	5		8	02	12
9	0										9	9.92	10
		4	1	1	1	1	1	1	0				
5.0	17.6	3	2	2	2	2	1	1	1		9.0	9.80	12
1	3	3	3	3	3	2	2	2	2		1	70	10
2	0	4	4	4	4	3	3	2	2		2	59	11
3	16.6	3	5	6	4	4	4	3	3		3	49	10
4	3	3	6	7	5	5	4	4	3		4	39	10
5	0	2	7	8	6	6	5	4	4		5	29	10
6	15.8	3	8	9	7	6	6	5	4		6	20	9
7	5	3	9	10	8	7	6	5	5		7	10	10
8	2	2									8	01	9
9	0										9	8.92	9

TABLE XLI—*Continued*

φ	d										φ	d	
10.0	8.83	9			9	8	7	6			15.0	5.90	3
1	74	9									2	82	8
2	66	8	1		1	1	1	1			4	74	8
3	57	9	2		2	2	1	1			6	67	7
4	49	8	3		3	2	2	2			8	60	7
5	41	8	4		4	3	3	2					
6	33	8	5		4	4	4	3			16.0	5.53	7
7	25	7	6		5	5	4	4			2	46	7
8	18	8	7		6	6	5	4			4	40	6
9	10		8		6	6	6	5			6	33	7
		7	9		7	6	6	5			8	27	6
11.0	8.03	7											
1	7.96	8									17.0	5.21	6
2	88	6									2	14	7
3	82	7									4	09	5
4	75	7									6	03	6
5	68	7									8	4.97	6
6	61	6											
7	55	6									18.0	4.92	5
8	49	7									2	86	6
9	42										4	81	5
		6				5	4	3			6	76	5
12.0	7.36	6									8	71	5
1	30	6		1		0	0	0					
2	24	6		2		1	1	1			19.0	4.66	5
3	18	6		3		2	1	1			2	61	5
4	12	5		4		2	2	1			4	57	4
5	07	6		5		3	2	2			6	52	5
6	01	5		6		3	2	2			8	48	4
7	6.96	6		7		4	3	2					
8	90	5		8		4	3	2			20.0	4.43	5
9	85			9		5	4	3			2	39	4
		7									4	34	5
13.0	6.78	4									5	30	4
1	74	5									8	26	4
2	69	5											
3	64	4									21.0	4.22	4
4	60	4									5	13	9
5	56	6									22.0	03	10
6	50	5									5	3.94	9
7	45	5											
8	40	4									23.0	3.86	8
9	36										5	78	8
		5									24.0	70	8
14.0	6.31	4									5	63	7
1	27	5											
2	22	4									25.0	3.56	7
3	18	4									5	49	7
4	14	4									26.0	42	7
5	10	4									5	36	6
6	06	4											
7	02	4											
8	5.97	5											
9	93	4											

TABLE XLI—*Continued*

φ	d	
27.0	3.30	6
5	24	6
28.0	18	6
5	13	5
29.0	3.07	6
5	02	5
30.0	2.97	5
5	92	5
31.0	2.88	4
5	83	5
32.0	79	4
5	75	4
33.0	2.71	4
34.0	63	8
35.0	2.56	7
36.0	49	7
37.0	42	7
38.0	36	6
39.0	30	6
40.0	2.25	5
41.0	20	5
42.0	15	5
43.0	10	5
44.0	05	5
45.0	2.01	4
46.0	1.97	4
47.0	93	4
48.0	89	4
49.0	86	3
50.0	1.82	4
51.0	79	3
52.0	76	3
53.0	72	4
54.0	69	3

	7	6	5	4
1	1	1	0	0
2	1	1	1	1
3	2	2	2	1
4	3	2	2	2
5	4	3	3	2
6	4	4	3	2
7	5	4	4	3
8	6	5	4	3
9	6	5	5	4

	3	2	1
1	0	0	0
2	1	0	0
3	1	1	0
4	1	1	0
5	2	1	1
6	2	1	1
7	2	1	1
8	2	2	1
9	3	2	1

φ	d	
55.0	1.67	2
56.0	64	3
57.0	61	3
58.0	59	2
59.0	56	3
60.0	1.54	2
61.0	52	2
62.0	49	3
63.0	47	2
64.0	45	2
65.0	1.43	2
66.0	41	2
67.0	39	2
68.0	38	1
69.0	36	2
70.0	1.34	2
71.0	32	2
72.0	31	1
73.0	29	2
74.0	28	1
75.0	1.26	2
76.0	25	1
77.0	24	1
78.0	22	2
79.0	21	1
80.0	1.20	1
81.0	18	2
82.0	17	1
83.0	16	1
84.0	15	1
85.0	1.14	1
86.0	13	1
87.0	12	1
88.0	11	1
89.0	10	1
90.0	1.09	1

Chapter 24

SUPPLEMENT

X-Ray Paper

The Powers x-ray paper is very much like semimatte double weight photographic paper. The emulsion of this paper is sensitive to Patterson 245 screens and has a speed comparable to Eastman F. The graininess is a little more apparent than when on film base.

The physical constants are:

O.I.L. speed	
500	23
E	
Density is 2.5	
Exposure time in seconds at 400 KV with 5 ma. at a distance of 12 feet.	22
Gamma	6.5
Latitude	
230	350
L	
Fog density is	1.8
The grain size is very coarse.	

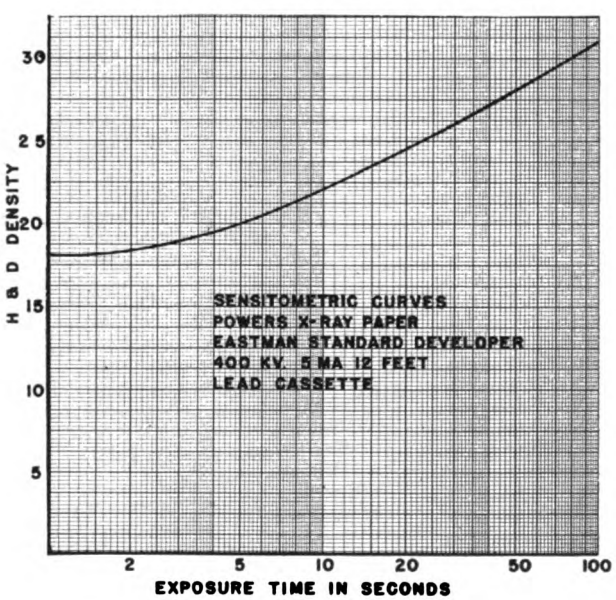


FIGURE 188

Qualities

It is viewed by reflected light, has excellent latitude, and is easily processed.

The tests were made on a 400 KV General Electric X-Ray Machine. The paper was developed in Eastman Standard Developer, was exposed in lead holders, and handled in darkroom same as film. The emulsion side should be placed in contact with back screen. All densities are measured by transmission on Ansco-Sweet Densitometer.

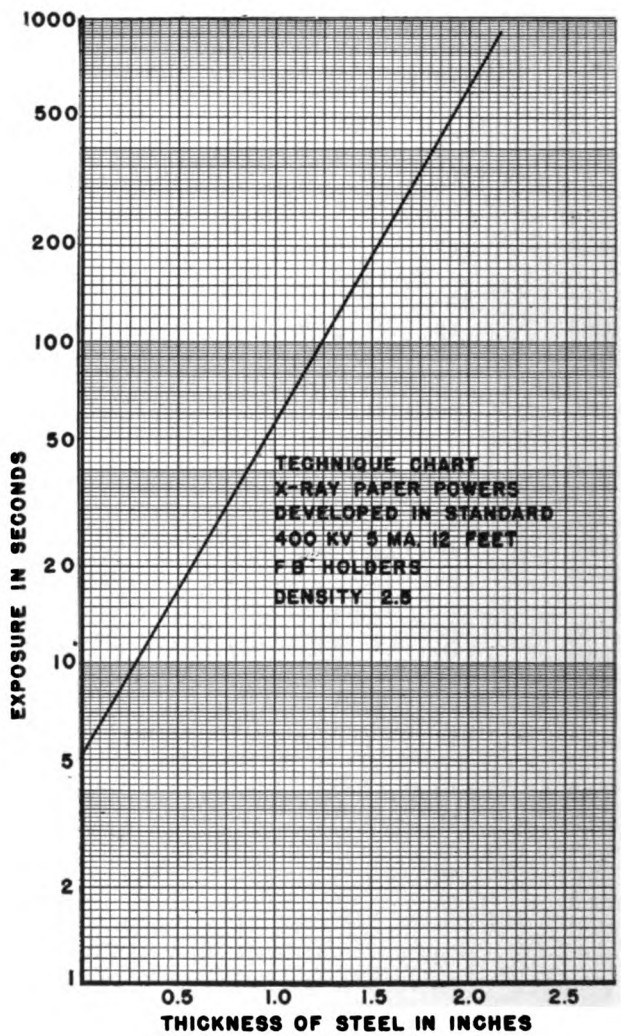


FIGURE 189

The results obtained indicate x-ray paper could be used to replace Eastman type F film, also may be used when it is desired to have a

radiograph that can be viewed by reflected light.

A comparison can be seen between the reproduction of the instrument exposed on Eastman A film and same instrument on paper. Both have been reproduced photographically.

The sensitivities at 1½ inches of steel at 400 KV with lead screens, developed in standard developer is 1.5%.

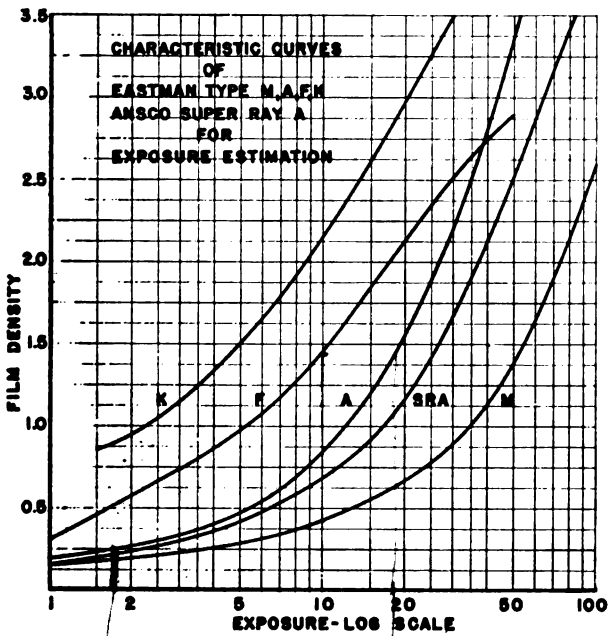


FIGURE 190

Estimation of Exposure

The normal method for obtaining exposure time is by technique charts or by half value method. However, occasionally an object is misjudged and another radiograph must be taken. Then there is the problem of exposure time. For the solution to this there is a set of characteristic curves for different films developed in standard, which is very helpful.

The exposure is plotted against density for 400 KV M.A. 6 feet on log scale. To use these curves the density of the first film must be known. The film is washed quickly and dried by a squeege then the density is read on Eastman Comparator Densitometer.

Using this density project, a line to the film curves used and from that point project line to the base. Follow same procedure for desired density. This will give the ratio between the old exposure and the new exposure so multiply this ratio times the actual exposure time to obtain the new exposure.

Example: 1st exposure 110 seconds
film density .9
desired density 1.5
film A developed in standard.

$$\frac{18}{11} \times 110 = 180 \text{ seconds.}$$

When a different developer is used another characteristic curve must be used.

Microdol Developer

Microdol is an Eastman photographic developer recommended for fine detail and excellent latitude qualities. The chemical formula for microdol has not been published but it is thought to be a metol or elon developer which makes it essentially the same as Eastman DK-20.

When microdol is used for x-ray film it is desired to have a developing time between 5 and 8 minutes so that to increase its speed, 10 ounces of kodalk is added to the 5 gallon solution. Instead of increasing the developing time as the solution is used it is more convenient to add replenisher. Microdel replenisher is used to build up the solutions; 20 ounces of kodalk is added to the 5 gallon solution of replenisher.

Microdol developer is not as stable as x-ray developers so it is necessary to control the developer speed and contrast. This control is obtained by using exposure strips which are run through the solution every 10 films to determine the amount of replenisher to be added. The density is measured and by the use of charts for developing time vs. density, an estimate of the developing time required for a definite density may be made. Or replenisher may be added to bring the density up to the desired level.

Occasionally with a fine grain developer the film will become mottled during processing so it is necessary to wash the film for two minutes in an acid solution or stop bath. Continuous agitation with an oscillating motion of the film is recommended while film is in developer.

If microdol is not available, DK-20 may be used.

DK-20 substitute formula

Water about 125° F	15 qt.
Elon	3 oz. 352 gr.
Kodak Sodium sulfite dessicated	4 lb. 12½ oz.
Kodalk	7 oz. 268 gr.
Kodak sodium thiocyanate	¾ oz.
Kodak potassium bromide	166 gr.
Cold water to make	5¾ gal.

DK-20 substitute replenisher

Water about 125° F.	15 qt.
Elon	5 oz.
Kodak sodium sulfite dessicated	4 lb. 2¼ oz.
Kodalk	13 oz. 20 gr.
Kodak Sodium thiocyanate	3 oz. 13 gr.
Kodak potassium bromide	290 gr.
Cold water to make	5 Gal.

The Bucky Grid

Figure 191 illustrates the use of the Bucky grid with the 250 KV unit. The exposure was increased by a factor of 2 to compensate for the reduction of scatter.

The results indicate more latitude and less undercutting. The lines are less sharp, however, due to the projection using a large focal spot and the vibration of the film when the Bucky is moving.

The Bucky may be used on the 2000 KV machine. The vibration, however, makes its use unadvisable.

Figure 61 illustrates the Bucky grid.

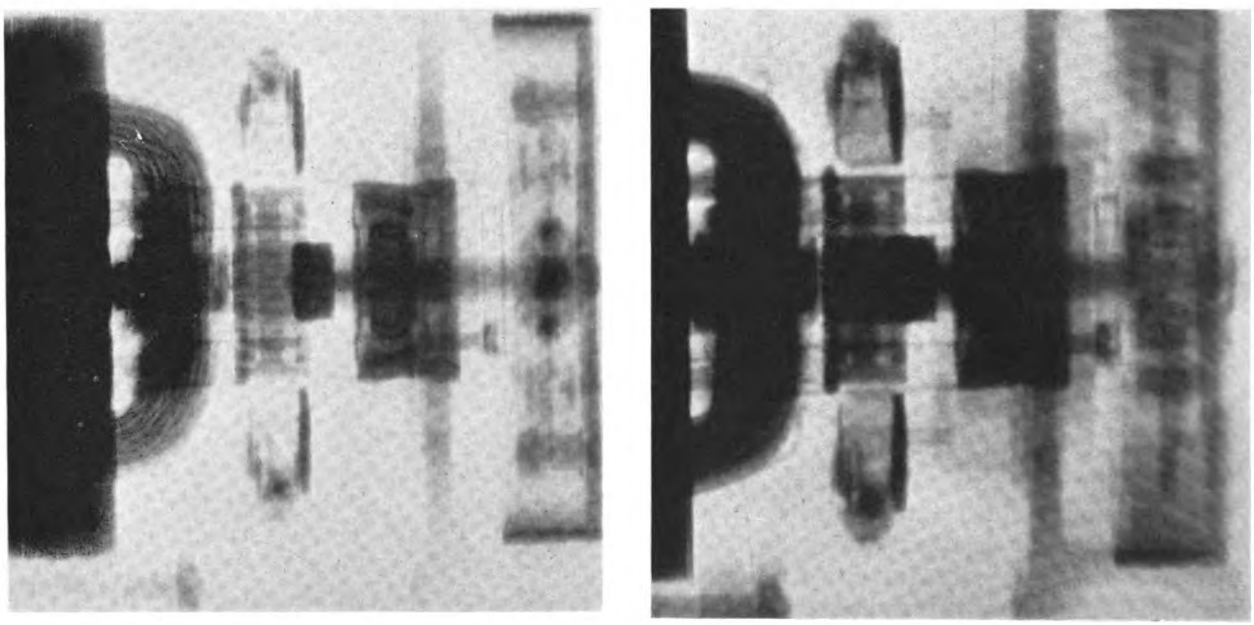


FIGURE 191. *Left:* without Bucky grid; *Right:* with Bucky grid

BIBLIOGRAPHY

BROWN, THOMAS B., *Foundation of Modern* physics, Wiley and Sons, London, 1940.

Bureau of Ordnance Publication #1179, 19 December 1944.

CHAMBERLAIN, W. E., "Fluoroscopes and Fluoroscopy", *Radiology*, Vol. 38, No. 4, April 1942.

CLARK, GEORGE L., *Applied X-Rays*, McGraw-Hill, New York, 1940.

COMPTON and ALLISON, *X-Rays in Theory and Experiment*, D. VanNostrand Co., New York, 1935.

GLASSER, QUIMBY, TAYLOR, and WEATHERWAX, *Physical Foundation of Radiology*, Paul B. Hoeber, New York, 1940.

HORNBECK, JOHN, *Investigation of the Absorption and Scattering by Steel of X-Rays in Region 1 to 2 MeV*, Massachusetts Institute of Technology, Cambridge, 1944.

National Defense Research Committee, *Three to Twenty Million Volt Radiography*, O.S.R.D. No. 3668, University of Illinois, 1944.

Principles of Operation and Electrostatic X-Ray Generator, Massachusetts Institute of Technology, Cambridge, Mass., 1944.

Radiography of Materials, Eastman Kodak Co., Rochester, N. Y.

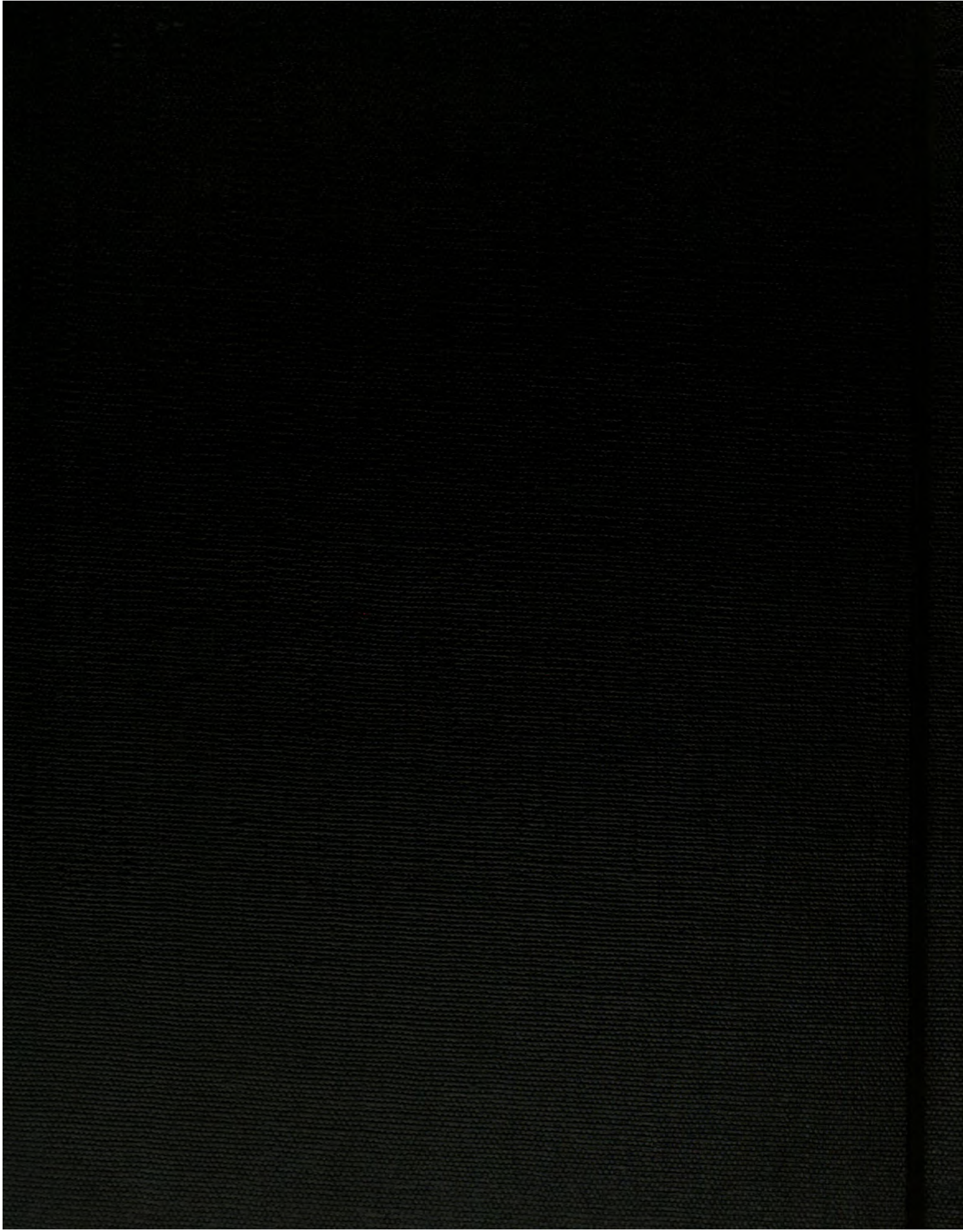
ST. JOHN and ISENBURGER, *Industrial Radoigraphy*, Wiley and Sons, 1934.

SHUNAMAN, FRED, "X-Ray Diffraction", *Radio-Craft*, July, 1944.

Three to Twenty Million Volt Radiography, Office of Scientific Research & Dev. Rep. No. 3075, University of Illinois, Urbana, Ill., 1944.

WEYL, WARREN, O'NEILL, *Radiologic Physics*, Charles C. Thomas, Baltimore, Md., 1941.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1946—699810

82 4 107FA3 2 013 1 BA 6169

UNIVERSITY OF MICHIGAN
3 9015 00049 9163